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Early Neuromuscular Stimulation and Mirror Therapy Interventions to Prevent Functional Loss During Immobilization of Distal Radius Fractures

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Abstract

Introduction: Mirror therapy (MT) and neuromuscular electrical stimulation (NMES) are interventions that mitigate impairments in pain, strength, range of motion (ROM), and function. Immobilization to treat distal radius fractures (DRF) can result in similar impairments. MT and NMES can be applied during immobilization for DRF as they do not require active movement of the affected extremity. This is the study to investigate the feasibility of in-home MT, NMES, MT+NMES interventions during the immobilization period for DRF.

Methods: Literature reviews were conducted to determine how NMES and MT have been used with musculoskeletal conditions. In-home MT, NMES, and MT+NMES interventions were developed for application during immobilization for DRF. A feasibility RCT was implemented to assess recruitment, adherence to interventions, retention to on-site visits, and limited efficacy testing. Semi-structured interviews were conducted 6-weeks post-DRF to gain insight into the patients perspective, the practicality and acceptability of the interventions. Pain, ROM, dexterity, function, and strength were measured at 3-, 6-, 8-, and 12-weeks post-DRF at the on-site visits. Electromyographic recordings were collected during contractions for wrist movements at 8- and 12-weeks to investigate potential mechanisms of change.

Results: MT and NMES can help reduce pain, improve function and strength for after periods of disuse. In-home MT, NMES, and MT+NMES interventions that are 10-minute sessions, three times a day, five days a week for the last three weeks of immobilization for DRF were developed. The in-home interventions demonstrate adequate feasibility at this interim analysis with an average of 5 participants recruitment per month, >80% adherence, and >80% retention for the intervention group and 75% retention for the control group. Limited efficacy testing demonstrates trends towards improvement for the intervention groups. Patients expressed the practicality and acceptance of the interventions. Participants attributed their recovery and facilitated outcomes to their participation in the study.

Discussion: Engaging in early interventions for DRF during immobilization appear feasible at this interim analysis. The full feasibility sample is required to determine whether the protocol can be implemented in a full RCT as it is or requiring modifications.

Keywords

Neuromuscular Stimulation, Mirror Therapy, Early Interventions, Distal Radius Fractures, Electromyography

Summary for Lay Audience

Fracturing the wrist usually requires a cast to be worn for at least six weeks to limit wrist movement and allow the bone to heal. The inactivity leads to loss of motor function (i.e. reduced strength and movement), which may require extensive rehabilitation and often leaves lasting impairments. Electrical stimulation activates the muscles of the arm and performing movements in front of mirror with the uninjured side are two strategies that can help recover from the resulting loss of motor function without having to move the injured arm. This research project aimed to develop interventions that can be applied during the casting period. The goal of this study was to determine if the interventions could be completed in-home after a wrist fracture. The project consists of 3-week in-home programs for three groups and standard care for the fourth group. One to activate the muscles of the arm, the other to perform movements in front of a mirror, and one group that does both together in hopes of improving recovery and shortening the time needed to heal. The in-home program was assessed for how well the protocol was followed on-site and at home, the practicality and if there was patient satisfaction with the interventions. Function, mobility, pain, fine motor skills, and strength was measured at four time points up to 12-weeks after the fracture. The recruitment and data collection for this study is ongoing. This study is the first to test these programs during casting for wrist fractures and will help decide if these programs should be used with all wrist fractures.

Co-Authorship Statement

Chapter 1: Grand Introduction

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1 Grand Introduction

This thesis focuses on mirror therapy and neuromuscular electrical stimulation as interventions for musculoskeletal conditions, with a particular focus on their in-home application during the immobilization period for distal radius fractures (DRF). The grand introduction with provide background information on mirror therapy (MT), neuromuscular electrical stimulation (NMES), home exercise programs, and distal radius fractures.

1.1 Mirror Therapy

MT is a technique used where a mirror is set up along the sagittal plane of the body with an affected extremity hidden behind the mirror out of sight and in a resting position. The mirror is positioned so the individual can see a reflection of the unaffected extremity, which provides the illusion that the affected extremity is unimpaired. Exercises are performed in front of the mirror with the affected extremity and the individual is instructed to watch the reflection and try to feel or imagine that the affected extremity is performing those exercises (1,2).

1.1.1 Proposed Mechanisms

Early investigations, with individuals experiencing phantom limb pain following an amputation, proposed that seeing the reflection of the extremity intact generates a representation for that extremity in the cortical network. Where movement of the unaffected side alone did not improve outcomes as seen with the mirror feedback interventions (3). It has been proposed that cortical reorganization is initiated during MT which allows for better integration of sensory feedback for pain free movement (4,5). Studies using transcranial magnetic stimulation (TMS) report that observing the reflection facilitates primary motor cortex excitability on the ipsilateral side and increases corticospinal pathway excitability (6–9). Increased excitability of the mirror neuron system (MNS) has also been implicated as a mechanism for the effect of MT. The MNS is a network of neurons that are distributed throughout cortical regions of the brain that allow for skill acquisition and motor learning by observing and imitating a movement (10–12).

1.1.2 Benefits of Mirror Therapy

MT is a beneficial treatment approach when active movement is not possible because it facilitates the neuromotor pathways involved in movement of the affected extremity in the absence of physical movement (6–9). MT is accessible, only requiring a mirror to complete, which provides flexibility for this intervention to be applied at home (13). A Cochrane systematic review reports MT is an effective intervention after a stroke producing improvements in motor function, activities of daily living, and reducing pain and motor impairments (13). While more recent systematic reviews report MT is equally as effective as other therapies (i.e., cross education, conventional exercise) at reducing spasticity following stroke (14) and is effective at producing improvements in activities of daily living and neglect symptoms (15). In addition to treating stroke populations, MT has been effective for treating phantom limb pain and chronic regional pain syndrome (CRPS) by reducing pain, improving motor function and participation in activities of daily living (3–5,13,15–17).

1.2 Neuromuscular Electrical Stimulation

NMES is a non-invasive modality where electrodes are placed on the skin and electrical current is passed through the electrodes to induce contractions in the underlying muscles. Parameters for maximizing the therapeutic application for NMES has been proposed to be a stimulation frequency of 50 to 100 Hz with biphasic rectangular pulses between 100 to 400 μs using the highest current intensity tolerable, but the effectiveness may be limited by the intrinsic muscle properties of the individual (18–20). A range of 25 to 50% of maximal voluntary contraction (MVC) force is proposed as the required intensity to have a therapeutic benefit in musculoskeletal conditions, but this can be lower in situations of muscle disuse as seen in intensive care units (19,21,22). When muscle activation is limited, NMES can be used passively over a resting extremity, to facilitate muscle activation during movement as seen with functional electrical stimulation (FES), and superimposed over active muscle contractions (18–20,23).

1.2.1 Proposed Mechanisms

NMES increases protein synthesis and reduces muscle atrophy, which are both repercussions from muscle disuse (24–27). NMES may provide an optimal motor unit recruitment pattern for atrophic conditions. During voluntary muscle activation motor

units are recruited from smallest to largest resulting in preferential recruitment of slow twitch muscle fibers before fast twitch muscle fibers (28). NMES is not selective in the recruitment of motor units and recruits all the motor units within that area of application at once (29,30). This may be advantageous in atrophic conditions, because fast twitch fibers are more vulnerable to atrophy (29,30). With NMES recruiting fast and slow twitch muscle fibers simultaneously, the fast twitch muscle fibers are recruited earlier than seen with active muscle contraction (25,29,30). In addition to muscle fiber activation, NMES also activates cutaneous fibers (19). NMES application has demonstrated neural adaptations that are proposed have an impact at the spinal and supraspinal level with increased corticospinal pathway excitability, activation of cortical and subcortical regions (31,32).

1.2.2 Benefits of Neuromuscular Electrical Stimulation

NMES is a useful treatment technique to maintain, preserve, and restore neuromuscular function following disuse (19). An advantage of NMES is the accessibility of the devices for public purchase and home use. NMES has been used to treat paresis, contractures, and spasticity in the upper extremity following stroke (23,33). Studies in the upper extremity have found improvements in strength (34–37), range of motion (ROM) (37–39), function (34,38,40–44), and cortical activation (42). Decreases in upper extremity spasticity (35,44) and pain (45,46) have also been reported. NMES applications in the lower extremity have primarily targeted the quadriceps after operations, fractures, and in healthy populations (23). NMES application after ACL repair has improved function (47,48) and reduced pain (49,50). NMES has been effective for reducing pain for patellofemoral pain syndrome (51–53). Applications of NMES for knee OA has resulted in decreased pain, stiffness, and improved strength and function (54–56). NMES has also been applied after knee and hip replacements demonstrating improved strength and function, reduced atrophy, and decreased pain (57–61). Klika et al (2022) also reported that use of NMES after knee replacement led to a faster return of function compared to controls.

More recent research using animal models has demonstrated the preventative role of NMES applications during immobilization (62–65). There is also evidence for electrical stimulation to improve fracture healing (66). Electrical stimulation via

wrist-bridging external fixation for DRF was shown to speed up callus formation and shorten the duration the external fixator was required (63–65,67). NMES applied via surface electrodes has also demonstrated improved mineralization and callus formation in animals (68).

1.3 Home Exercise Programs

Home exercise programs are an important part of physiotherapy programs to reduce disability and improve symptoms in musculoskeletal conditions (69). Home exercise involves patients being prescribed with a series of exercises to be done at home. The emphasis with home exercise programs is self-management of the individuals' condition given that patients spend more time without their physical therapist than with them. The effectiveness of home exercise programs is limited to the adherence to the program.

1.3.1 Adherence to In-Home Rehabilitation

The world health organization defines adherence to a program as the extent of an individuals' engagement with the recommendations provided by a healthcare provider. The level of engagement that is deemed adherent is not clearly defined in the literature. Adherence rates range between 30 and 50% for home exercise programs to treat musculoskeletal conditions (70–74). A challenge in assessing adherence is the lack of monitoring and reporting. In a literature review for physiotherapy services for DRFs, 23 studies were identified and none reported on adherence to treatment (75). Adherence to home exercise programs can improve outcomes and potentially decrease the financial burden of treatment for patients and funding bodies by reducing the number of physiotherapy visits required (76). Rapport between the patient and physical therapist, education, goal setting, effective communication, individualization of programs, individual motivation, and treatment efficacy are factors that can impact adherence rates (77–79).

1.4 Distal Radius Fractures

DRF are a fracture of the wrist affecting the distal radius. DRF can also be classified Colles, Barton, Smith, and Hutchinson/Chauffer fracture based on the characteristics of the fracture (80–83). There is a bimodal distribution with more younger adults sustaining DRF from impact during high-energy trauma (e.g. car accident, contact sport) and low-

energy falls from standing height (onto an outstretched hand) are more prevalent for older adults, particularly during winter months (84–86).

1.4.1 Epidemiology

DRF are the most common fractures in adults accounting for up to 17.5% of all adult fractures (87–89). Incidence rates of DRF are increasing (90–92). A contributing factor is the aging population with greater rates of low bone density and osteoporosis (86,89,92,93). In the older population, DRF are up to 4x more common in the females than males (94). In a national Swedish fracture registry study, the highest incidence of DRF is in older women from a low-energy fall in their residence and they were treated non-operatively (89).

1.4.2 Management Strategies

DRF are operatively managed or conservatively managed with closed reduction and immobilization in a cast (95). Minimally displaced fractures are managed conservatively about one third of the time (94). The standard immobilization period for DRF is six weeks to allow for callus formation, bone and soft tissue healing (96,97). During casting, standard practice is to maintain range of motion in the upper extremity above and below the cast (98). In recent years, more research has looked at shorter immobilization periods for early mobilization. Comparison of shorter casting periods, as little as 10 days, to the standard duration (~6 weeks) demonstrates no group differences for patient-reported functional outcomes, pain scores, CRPS, secondary displacement, or complications up to nine months after fracture (99–102).

The goals of these interventions are to support fracture healing, improve function, and reduce pain (103). Factors influencing the capacity to recover and treatment approach for DRF include age, risk of complications, and severity of the fracture (104–107). Predictors for unstable DRF include > 60 years of age, dorsal comminution, >20° dorsal angulation, associated ulnar fracture and fracture into the radiocarpal joint (108). Unstable fractures require operative management (108,109). Operative management approached have been increasing in recent years (87,92,110,111). Although radiological outcomes are improved with operative management, comparable functional outcomes are reported for operative and conservative management (107). Conservative management of unstable fractures in

older adults can produce good clinical outcomes even with mal-alignment due to lower functional demands (104,106,112). Many months of physical therapy are required after operative and conservative management for DRF to address the reduced muscle mass, mobility, strength, pain, and function (113–117).

1.4.3 Rehabilitation

Regardless of management strategy, it typically takes three to six months to recover motor function, strength, and movement (115,118,119). A small group of patients experience minor disability and pain persisting years after the DRF (113,115,119–122). As a result of the DRF, individuals experience reduced wrist ROM, grip strength, dexterity, and increased pain (113,115,123). The primary goal of rehabilitation is to improve address these impairments using modalities, manual therapy, and exercise programs (98,124,125). Exercise programs incorporate exercises to improve range of motion, dexterity, and strength. Rehabilitation has substantial impacts on reducing impairments, facilitating recovery times, and limiting the amount of time taken off work (95).

1.4.4 Outcome Assessment

Objective measures used to monitor progress include grip strength, ROM, and dexterity (95,126,127). Changes in range of motion and grip strength after DRF can have negative implications for dexterity (128). After a DRF, the clinically relevant change in grip strength is 6.5 kg (129). Grip and wrist extension are strong ROM measures for functional scores (130).

Valid and reliable patient reported functional outcomes measures used to monitor progress with DRF recovery include the Disabilities of the Arm, Shoulder, and Hand (DASH), QuickDASH, and Patient-Rated Wrist Evaluation (PRWE) (131–133). After DRF there are correlations between function and quality of life (QoL). QoL is important to assess as it is impacted by management approach for the DRF and factors like age (134).

The EuroQol-5D (EQ-5D) is a health-related quality of life (HRQoL) measure that captures self-reported problems with mobility, self-care, usual activities, pain/discomfort and anxiety/depression. EQ-5D visual analog scale (VAS) has individuals rate their

overall health from zero “the worst health you can image” to 100 “the best health you can imagine”(135). The EQ-5D is responsive in DRF populations (136,137).

1.4.5 Implications of DRF

DRF have financial implications for the healthcare system and individuals’ that sustained the DRF. An estimated $535 million in Medicare is spent annually for DRF (138,139). This is expected to increase dramatically from the increasing rates of DRF with the aging population and increasing trend for operative management (139). Most individuals with DRF must take a leave from work. Only 20% of individuals that have sustained a DRF report no loss of time at work (115,140). Greater intensity of pain, self-reported disability, age, fracture of the dominant wrist, work demand, and management approach are predictors for the duration of leave from work. The median time for leaves from work in females is 8 weeks compared to 4 weeks for males (115,140).

1.5 Electromyography

Following disuse conditions, the loss in muscle strength has exceeded the degree of muscle atrophy (141–143). A proposed mechanism of this decrease in strength is due to neural adaptations with reduced coordination of recruitment and modulation of motor units (MUs) (141). There is evidence to suggest certain muscles are more susceptible to these neural adaptations from disuse and a proposed mechanism is the composition of type I and type II MUs in the muscles. Type I MUs are slow twitch and regarded as fatigue resistant while type II MUs are fast twitch allowing for a quick increase force production but more susceptible to fatigue (144). There are conflicting reports from individual studies to suggest type II MUs are more vulnerable to disuse, while others suggest type I MUs are more vulnerable (145,146). The context of the disuse and level of muscle activity prior to the condition leading to disuse may be contributing factors. A systematic review and meta-analysis including 42 studies noted a reduction in type I fibers and increase in type II fibers with reduced muscle activity (147). Assessing changes in type II MU recruitment can be done during fatiguing contractions using electromyography (EMG).

EMG is a technique that can be used to measure and analyze myoelectric signals. There is indwelling EMG that requires a needle/fine-wire electrode being inserted

into the muscle to record. A less invasive method is surface EMG (sEMG) where electrodes are placed on the skin over the muscles of interest. Frequency and amplitude analyses of the EMG can be used to assess MU recruitment and neuromuscular fatigue in the underlying muscles (148). Mean power frequency (MPF) and root mean square (RMS) are two measures that can be determined from EMG recordings to reflect MU recruitment strategies and the sum of MU recruited determining the muscle contraction intensity (149–151). An inverse relationship can be seen between MPF and RMS during fatiguing contractions (152–154). MPF decreases during sustained contractions as a result of type II MU fatigue (155–158). RMS increases as a reflection of more type II MUs being recruited in an attempt to maintain the force of the contraction; most likely type II MUs for a quick response (159–165). Differences in EMG characteristics have been correlated with function, as measures by the PRWE, after DRF (166).

1.6 Gaps in the Literature

NMES and MT are interventions that have been used with populations that experience impairments from periods of disuse of an extremity, but there have been limited applications as preventative measures during immobilization of an upper extremity. During immobilization of an upper extremity, no studies have applied NMES and only one study has applied MT during immobilization after a carpal tunnel release (167,168). Application of NMES and MT interventions during disuse have been shown to improve motor function, strength, range of motion and reduce pain (13,34,37,45,46,169). Immobilization for DRF results in impairments with motor function, muscle mass, strength, range of motion, and pain (113–117,123).

There have been limited investigations using sEMG to provide insight into potential mechanisms for the resulting impairments after DRF (166,170). Establishing a way to promote activation of the neural pathways, while still protecting the fracture to promote bone healing could help improve outcomes and facilitate recovery. NMES and MT may be feasible options to apply during the immobilization period for DRFs because they do not require active movement of the affected wrist, promote activation of neural pathways involved in active movement, and they can be done in-home.

Assessing EMG characteristics after DRF may provide insight into explain differences in objective and patient reported outcomes in response to MT and NMES.

1.7 This Thesis

This thesis was the first to explore applications of MT and NMES during immobilization for DRF. The goal was to develop MT, NMES and combined MT+NMES interventions that can be done in- home during the immobilization period for DRF. Literature reviews were the first steps to understand how NMES has been applied during immobilization and how MT has been used for hand/wrist rehabilitation. Several research questions were addressed in a feasibility randomized controlled trial with a four group design. The feasibility of the in-home interventions was investigated, which included a patient perspective of the interventions with semi-structured interviews. Potential mechanisms for the outcomes were investigated using EMG. The sample size calculated for the feasibility study was 72 with 18 in each group. Recruitment for the project is ongoing and this thesis reports on recruitment and data collection from January 2024 to June 2024.

1.7.1 Manuscripts Prepared for This Thesis

Reischl S, Ziebart C, MacDermid JC, Grewal R, Schabrun SM, Trejos AL. Application of neuromuscular electrical stimulation during immobilization of extremities for musculoskeletal conditions: A scoping review. *In press with the Journal of Bodywork and Movement Therapies*

Reischl S, MacDermid JC, Grewal R, Schabrun SM, Trejos AL. Feasibility of in-home neuromuscular electrical stimulation and mirror therapy interventions during immobilization for distal radius fractures: a randomised controlled trial protocol. *Under review with BMJ Open*

Reischl S, Furtado R, MacDermid JC, Grewal R, Schabrun SM, Trejos AL. Effectiveness of mirror therapy to treat musculoskeletal injuries of the hand and wrist: a systematic review. Under review with *Journal of Hand Therapy*

Reischl S, MacDermid JC, Grewal R, Schabrun SM, Trejos AL. Patient perspective of in-home mirror therapy and neuromuscular electrical stimulation

interventions for distal radius fracture: a qualitative study. *Ongoing recruitment and data collection.*

Reischl S, MacDermid JC, Grewal R, Schabrun SM, Trejos AL. The feasibility of in-home mirror therapy and neuromuscular electrical stimulation interventions during immobilization of distal radius fractures: Quantitative assessment. *Ongoing recruitment and data collection.*

Reischl S, MacDermid JC, Grewal R, Schabrun SM, Trejos AL. Implications of mirror therapy and neuromuscular electrical stimulation on immobilization induced electromyographic changes after distal radius fracture. *Ongoing recruitment and data collection.*

2 Application of neuromuscular electrical stimulation during immobilization of extremities for musculoskeletal conditions: A scoping review

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2.1 Abstract

Introduction: Neuromuscular electrical stimulation (NMES) is effective at improving outcomes after periods of disuse. It is unclear if NMES can be applied during periods of disuse to mitigate resulting impairments from disuse. This review aims to explore the state of the literature applying NMES during the immobilization of musculoskeletal conditions.

Methods: For this scoping review the keywords used to search PubMed, Scopus, CINAHL, and Proquest Dissertations and Thesis were related to electrical stimulation, musculoskeletal injury, and immobilization. Data extracted included study design, sample characteristics, immobilization protocol, intervention, stimulation parameters, outcome measures, and results. Quality assessment was completed for all included studies.

Results: Six studies with 127 participants were included. The musculoskeletal conditions addressed were anterior cruciate ligament repair and tibia fracture. NMES duration ranged from 40 minutes to eight hours a day for four to six weeks during immobilization. NMES application improved quadriceps atrophy and strength outcomes in four studies.

Discussion: The body of literature is limited to two patient populations, only a small sample of cohort studies, physiological outcomes, and all studies were published before 1989. The models used in these studies are outdated, so new models (i.e. distal radius fracture) are proposed for future investigations applying NMES to improve outcomes following immobilization in musculoskeletal populations.

Conclusion: This study highlights a substantial gap in the literature and that further investigation into NMES application during immobilization for musculoskeletal conditions is warranted.

Keywords: neuromuscular electrical stimulation, immobilization, musculoskeletal, atrophy, strength

2.2 Introduction

Prolonged immobilization is often necessary for treating upper and lower extremity musculoskeletal conditions. A typical immobilization period for bony and soft tissue healing is approximately six weeks. This time frame is needed to allow for callus formation, soft tissue and bone healing (96,97). Unfortunately, immobilization can have profound negative effects on muscle mass, strength, mobility, and function (113–117), requiring many months of physical therapy to recover. In recent years there has been increased interest in the application of electrical stimulation modalities to address immobilization induced impairments. One strategy explored is electrical muscle stimulation (EMS) or neuromuscular electrical stimulation (NMES).

NMES is often used as an adjuvant therapy to standard physical therapy to aid in recovery (23). NMES can be superimposed over active muscle contractions or used as a passive modality on an inactive muscle to evoke a contraction without active movement (23). Research investigating NMES use on upper extremities has focused primarily on stroke populations in cases of hemiparesis, spasticity, and/or contractures affecting that extremity (23,33). Following a stroke, NMES is often used passively or during movement as functional electrical stimulation (FES) due to a lack of activation in the target muscles (171). NMES applications on the lower extremities have primarily focused on the quadricep muscles often in healthy populations, following knee operations, and after hip fractures (23). This body of literature has focused on implementing NMES superimposed over active muscle contractions. NMES studies for upper and lower extremities have demonstrated improvements in strength (35,37,56,58), range of motion (ROM) (37), function (42,56,58), and cortical activation (42). Decreases in upper extremity spasticity (35), lower extremity stiffness (56), and pain (56,58) have also been reported.

However, there may be a theoretical foundation for the use of NMES during immobilization for musculoskeletal conditions to potentially mitigate the resulting impairments from disuse. NMES has been successfully applied in the ICU to reduce muscle atrophy and maintain strength from disuse disuse (172,173). The existing

evidence for applying NMES during disuse conditions has focused on populations where the extremity, and neuromotor pathways targeted with the intervention, may be impacted by the condition (e.g., after stroke, in a coma). It would be interesting to investigate the effect of NMES when the extremity is inactive, but the neuromotor pathways are not directly impacted from the condition, as seen with immobilizations due to a musculoskeletal injury. Therefore, the aim of this scoping review was to describe the state of the literature investigating the application of NMES during the immobilization of upper and lower extremity musculoskeletal conditions to mitigate the resulting impairments.

2.3 Methods

2.3.1 Literature Search and Article Identification

The literature search was initiated by combining keywords (“electrical stimulation” OR “NMES” OR “neuromuscular electrical stimulation”) AND (“musculoskeletal” OR “muscle” OR “bone” OR “fracture”) AND (“immobilize” OR “immobilization” OR “cast” OR “splint”) in Pubmed, Scopus, CINAHL, and Proquest Dissertations and Thesis in October 2023. The specific search strategy can be seen in Appendix A. Next a manual search was conducted from reference lists of identified studies. Articles were included if the full text was available in English, an upper or lower extremity was immobilized during the NMES application, and NMES was applied with surface electrodes. Articles were excluded if they were not available in English, applied NMES to upper or lower extremities outside of the immobilization period, participants had a neurological condition that could impair neuromotor pathways, and/or electrical stimulation was applied invasively. Study protocols and animal studies were also excluded.

2.3.2 Data Evaluation and Analysis

Data extraction included documenting the following: 1) study design, 2) sample characteristics, 3) immobilization protocol, 4) intervention, 5) stimulation parameters, 9) outcome measures, and 10) results. The PRISMA checklist for scoping reviews is available as Appendix B. The Joanna Briggs Institute (JBI) Critical Appraisal Tools for Cohort Studies was used to appraise the quality of the included articles. Descriptive synthesis was used to evaluate the studies.

2.4 Results

The initial database search resulted in identification of 471 articles. After duplicates were removed and screening was complete, six articles were deemed eligible and included in the review. The PRISMA flow diagram is included to breakdown the study selection process (Figure 1). The combined sample size is 127 with individual study sample sizes ranging from 8 to 38 patients (24,26,174–177).

2.4.1 Quality Assessment

All six of the included studies were prospective cohort studies rated with sufficient quality to be included in the review using the Joanna Briggs Institute (JBI) Critical Appraisal Tools for Cohort Studies (Appendix C). The studies were conducted over the years 1979 to 1988. The lack of blinded outcome assessment suggests that there is a risk of bias for the intervention effects and an insufficient pool of evidence for a robust systematic review or meta-analysis at this time.

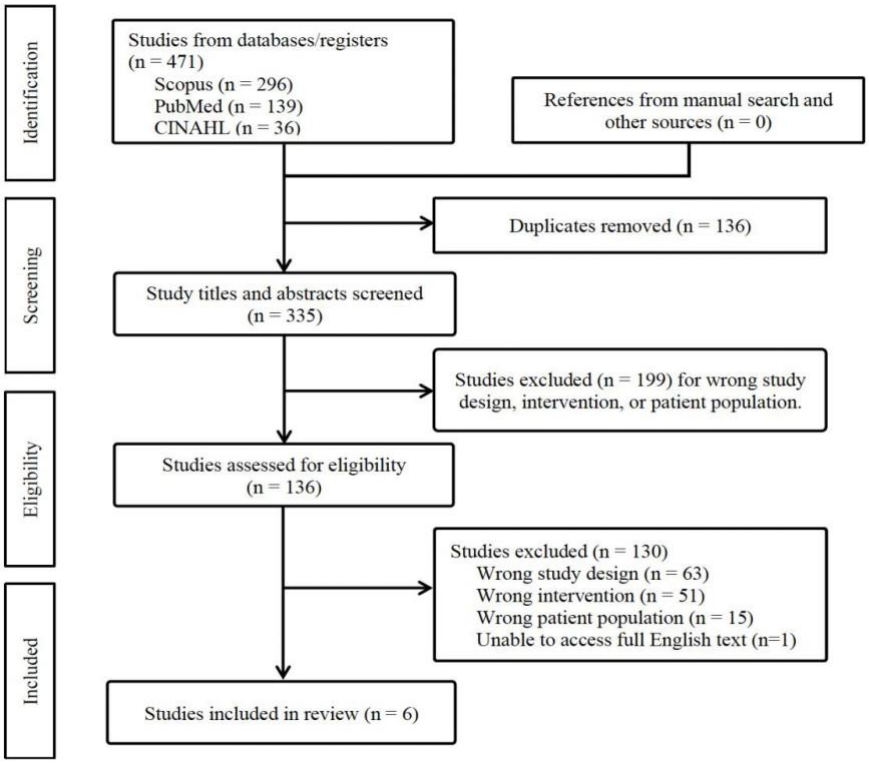

Fig. 1 PRISMA flow diagram outlining the study selection process.

2.4.2 Patient Characteristics and Indications

Five of six studies investigated patients that underwent ACL reconstruction, representing 83% of the patients included in this review (Gibson JN et al., 1988). One study investigated patients that sustained a tibia fracture representing the remaining 17% of the patients included in this review (175). Of the 121 patients where sex was specified, 69% were male (24,26,175–177). One study did not specify the sex of the eight patients (174). The patient age ranged between 18 to 76 years across the six studies (24,26,174–177). Individual study characteristics are outlined in Table 1.

Table 1. An overview of the included articles study design and sample characteristics.

Author	Study Design	Sample Characteristics
Arvidsson et al. (1986)	Cohort	38 patients who underwent ACL reconstruction - Sex: 18 M, 20 F - Groups (n): EMS M (8), CON M (10), EMS F (10), CON F (10) - Mean age (range): EMS M 27 (22 to 40) y, CON M 26 (20 to 31) y, EMS F 24 (18 to 30), CON F 21 (18 to 27) y
Eriksson & Häggmark (1979)	Cohort	8 patients who underwent ACL reconstruction - Sex: not disclosed - Groups (n): EMS (4), CON (4) - Mean age (range): EMS 27 (24 to 34) y, CON 28 (20 to 40) y
Gibson, Smith, & Rennie (1988)	Cohort	21 patients who sustained a tibia fracture - Sex: 21 M - Groups (n): EMS (7) CON (14) - Mean age (range): EMS 26 (18 to 49) y, CON 48 (19 to 76) y
Morrissey et al. (1985)	Cohort	15 patients who underwent ACL reconstruction - Sex: 15 M - Groups (n): EMS (8), CON (7) - Mean age (range): EMS 23 (17 to 30) y, CON 27 (23 to 31) y
Sisk et al. (1987)	Cohort	22 patients who underwent ACL reconstruction - Sex: 13 M, 9 F - Groups (n): EMS (11), CON (11) - Mean age: EMS 23.4 +/- 7.5 y, CON 23.9 +/- 9.2 y
Wigerstad -Lossing	Cohort	23 patients who underwent ACL reconstruction - Male: 16 M, 7 F

et al. (1988)		- Groups (n): EMS (13), CON (10): Mean age (range): EMS 28 (21 to 45) y, CON 26 (21 to 33) y

*M = male, F = female, ACL = anterior cruciate ligament, EMS = electrical muscle stimulation group, CON = control group, y = years

2.4.3 Immobilization Procedures

The lower extremity was immobilized in an above knee cast, at 10˚ to 45˚ of flexion for four to six weeks (24,26,174–177). All casts had distal and proximal holes cut over the quadriceps to allow for electrode placement (24,26,174–177). Individual immobilization procedures and landmarks for the hole cut in the casts are presented in Table 2.

2.4.4 NMES Intervention and Parameters

Intervention duration ranged from 40 minutes (min) to eight hours in a day, three to seven times a week, for four to six weeks. Stimulation pulse rate settings ranged from 30 Hz to 200 Hz. Reported rise times ranged from 0.5 to four seconds (sec) and fall times from two to four sec. Duration of stimulation ranged from two to 20 sec and rest time ranged from five to 50 sec. Five of the studies reported a stimulation intensity ranging from a palpable or visible contraction to a strong sustained or tetanic contraction (24,174–177). One study had patients actively contract while the NMES was on (26). Table 2 presents the NMES intervention and parameters available for extraction for each individual study. The researchers did not report if there were adverse events in any of the studies.

Table 2. Intervention and stimulation parameters for each study.

Author	Immobilization Protocol	Intervention	Stimulation Parameters
Arvidsson et al. (1986)	- 1 week in posterior splint with knee at 45° flexion then 5 weeks in cylinder cast from ankle to groin with knee at 45° flexion; Stimulation windows cut in cast ~8 cm above patella and ~5 cm below inguinal ligament.	25–30 min, 3 times a day for 5.5 weeks	PR=40 Hz, PW=300 µs Rise=2 sec, on=20 sec, fall=4 sec, rest=35 sec Intensity – strong sustained

			contraction
Eriksson & Häggmark (1979)	- 5 weeks in cylinder cast from ankle to groin with knee at 10° flexion; Stimulation window over distal quadriceps.	1 hour daily, 5 times a week for 4 weeks	PR=200 Hz On=5 sec, rest=5 sec Intensity – tetanic contraction
Gibson, Smith, & Rennie (1988)	- 6 weeks in long leg cast; Stimulation windows over 20 cm apart over quadriceps.	1 hour daily for 6 weeks	PR=30 Hz, PW=300 µs On=2 sec, rest=9 sec Intensity – visible contraction
Morrissey et al. (1985)	- 6 weeks in cylinder cast from ankle to groin with knee at 45° flexion; Stimulation windows over middle quadriceps ~15 cm distal to anterior superior iliac spine and vastus medialis motor point.	8+ hours daily for 6 weeks	PR=50 Hz, Rise=4 sec, on=10 sec, fall=2 sec, rest=50 sec Intensity – tetanic contraction
Sisk et al. (1987)	- 2 weeks in plaster cast (ankle to groin), knee flexed at 45-50° → 2 weeks in fiberglass cast → 2 weeks in cast/brace with limited knee flexion (45 to 90°); Stimulation windows for electrodes over quadriceps ~10 cm proximal to patella on vastus lateralis and ~5 cm distal to inguinal ligament.	8 hours daily for 6 weeks	PR=40 Hz, PW=300 µs Rise=0.5 sec, on=10 sec, rest=30 sec

* PR = pulse rate, PW = pulse width, sec = seconds

2.4.5 Outcomes Evaluated

2.4.5.1 Quadriceps Atrophy

Individual results for the outcome measures are reported in Table 3. Two studies used thigh circumference as a measure for atrophy (174,176). Eriksson & Häggmark (1979) used a grading criterion to classify the groups based on muscle force and thigh circumference demonstrating that the NMES group produced greater muscle force and had less reduction in thigh circumference than the control group. Morrissey et al. (1985)

reported a reduction in thigh circumference of 10% for the NMES group and 13% for the control group. The differences identified between the groups in both studies were not statistically significant.

Three studies used computed tomography to measure quadriceps cross sectional area (CSA) to assess atrophy (24,26,175). The reduction in quadriceps CSA ranged from 5 to 23% for the NMES groups and from 17 to 29% for the control groups (24,26,175). Two studies reported significantly less reduction in quadriceps CSA in the NMES groups when compared between groups (24,26). Gibson et al. (1988) did not analyze the change in quadriceps area between groups but did report a significant reduction in quadriceps CSA for only the control group. Arvidsson et al. (1986) also analyzed changes in quadriceps CSA by sex. There was no difference in quadriceps CSA for the male NMES and control groups. However, the female control group experienced a greater loss of quadriceps CSA than the NMES group (31.4% vs. 15.6%, $p<0.001$).

2.4.5.2 Quadriceps Strength

Three studies measured isometric torque production in the quadriceps to assess strength (26,176,177). When quadriceps strength was measured following cast removal there was a 39–60% decrease for NMES, which was significantly reduced compared to the 58–80% decrease for control group (26,176). Sisk et al. (1987) did not report group differences in quadriceps strength.

Table 3. Study outcome measures and results.

Author	Outcome Measures	Results
Arvidsson et al. (1986)	Quadriceps CSA	Quadriceps CSA when M and F subjects were combined was 14.7% for EMS and 24.3% CON ($p<.01$). For the M groups, quadriceps CSA decreased 13.5% for EMS and 17.2 % CON which was not significantly different. In the F groups, quadriceps CSA decreased 15.6% for EMS and 31.4% CON ($p<.001$).
Eriksson & Häggmark (1979)	Thigh circumference	Thigh circumference was presented with a grading system that included muscle force interpretation. EMS had good muscle force and 1 to 2 cm of atrophy compared to considerably

		reduced muscle force and 3 to 4 cm of atrophy in the CON.
Gibson, Smith, & Rennie (1988)	Quadriceps CSA	Quadriceps CSA was significantly reduced by 17% for CON. There was a 5% reduction in CSA for the EMS group, but this was not significant.
Morrissey et al. (1985)	Thigh circumference, isometric quadriceps strength	- Thigh circumference decreased 10% for EMS and 13% for CON. Not significantly different. - Immediately after cast removal quadriceps torque production decreased 60% for EMS and 80% for CON (p<.05).

*M = male, F = female, EMS = electrical muscle stimulation group, CON = control group, CSA = cross sectional area

2.5 Discussion

This scoping review found a limited and outdated pool of research that provides mostly positive findings that NMES interventions during the four to six weeks of immobilization, following ACL reconstruction and tibia fracture, can be used to mitigate loss of quadriceps strength and atrophy. The immobilization procedures and stimulation parameters were similar across studies, but intervention duration varied from 25 min to 8 hours a day. In comparing treatment duration of the studies, increasing NMES treatment duration above 90 minutes a day does not appear to produce additional benefits for maintaining quadriceps strength or reducing atrophy during immobilization. Of the studies reporting reduced loss of quadriceps strength for the NMES group, one intervention was NMES application for a cumulative 40 minutes a day, 3 days a week for 6 weeks (26) while the other study was applying NMES 8+ hours a day, every day for 6 weeks (176). The studies reporting reduced atrophy in the NMES groups compared to the control group all applied NMES for less than 90 minutes a day (24,26,175).

There was heterogeneity in the measures used to assess atrophy, but four of the five studies that assessed atrophy reported 3 to 12% less atrophy in the quadriceps when NMES was applied during immobilization. One study assessed atrophy using thigh circumference, but did not report a significant difference between the NMES and control group, despite greater quadriceps strength retention in the NMES group (176). Thigh

circumference may not be a good indicator for muscle atrophy as the composition of the thigh may change (i.e., subcutaneous tissue and muscle mass) (24). The control group could have greater subcutaneous tissue and less muscle mass retained while the NMES group may have less subcutaneous tissue and more muscle mass. NMES has been reported to increase protein synthesis thereby providing a great option for maintaining muscle mass in immobilized extremities (25). During immobilization it is proposed that muscle atrophy is a repercussion of reduced protein synthesis from disuse of the muscle (27). Greater muscle mass retention in some of the included studies corresponded with greater strength reported in the NMES groups.

The included studies were all published before 1989. There is more recent research demonstrating the preventative role NMES can have during immobilization, but this has been investigated using animal models (62,65). NMES has been used more recently following ACL reconstruction, but the patients are no longer prescribed long leg casts post operatively and so the individuals are being encouraged to actively use the leg for rehabilitation. Voluntary muscle activation is the preferred method for strengthening and maintaining muscle mass compared to NMES when available. Future studies investigating the effectiveness of NMES for musculoskeletal conditions should use models that currently use immobilization as standard of care for treatment so NMES can be applied when active movement is unavailable.

An example of this is a distal radius fracture (DRF) in the wrist. DRFs are one of the most common fractures in adults and having impairments that can persist even after one year (89,178). DRFs are a great model to investigate the potential effects of NMES during immobilization due to it requiring four to six weeks of immobilization (179) and DRFs being more prevalent in females (90). In one of the included studies, females demonstrated a greater degree of muscle atrophy following immobilization and a lesser degree of atrophy in the NMES group compared to the control group that were not seen in the male groups (24). Finding strategies to mitigate impairments following DRF could have substantial impact for recovery in this population. To determine the impact of NMES on recovery, functional and patient reported outcomes are important to assess rather than physiological changes alone.

The studies included in this review provide evidence for the benefits of NMES during immobilization of the lower extremity to mitigate losses in quadriceps muscle mass and strength. This review highlights substantial gaps in the literature with only six articles included, all the articles are prospective cohort studies, published before 1989, only focused on the lower extremity and physiological outcomes. The quality of the evidence is limited, but the existing literature and theoretical foundation for the benefits of NMES applied during immobilization warrant further investigation with randomized controlled trials.

2.6 Conclusion

There is limited evidence for the use of NMES during immobilization of the knee, but there are promising findings for NMES mitigating losses to quadriceps strength and atrophy. It is unclear whether this applies to other areas of the body, so further investigation is warranted. Future studies should consider more appropriate models given current treatment protocols for immobilization (e.g., distal radius fractures), should implement higher quality studies with blinded assessment and larger samples, and should assess outcome measures that can also capture the functional implications of physiological adaptations.

3 Effectiveness of mirror therapy to treat musculoskeletal injuries of the hand and wrist: a systematic review.

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3.1 Abstract

Introduction: Mirror therapy (MT) is an effective intervention for improving outcomes when an affected extremity has severe movement restrictions or pain. Upper extremity musculoskeletal conditions often require periods of immobilization where the extremity is not used and there are resulting impairments from the disuse. The aim of this review was to investigate the effects of MT interventions on musculoskeletal conditions of the hand/wrist.

Methods: This systematic review was conducted in accordance with Cochrane and PRISMA guidelines and registered with Open Science Framework (DOI:10.17605/OSF.IO/SVF6A). The search was conducted in EMBASE, PubMed, and Scopus in April 2024. Search terms included a combination of hand and wrist injuries, MT, pain, range of motion (ROM), strength, and function. Studies were included if they were randomized controlled trials, had populations being treated for musculoskeletal conditions of the hand/wrist, included a MT intervention, and assess pain, strength, ROM, and/or function. Studies were excluded if they were not available in English and/or the populations had neurological symptoms impacting their hand/wrist. Descriptive synthesis was used to summarize the data for interventions and outcomes. The Cochrane RoB 2 tool was used for quality assessment.

Results: This systematic review was conducted in accordance with Cochrane and PRISMA 2020 recommendations. The protocol for this review was registered with Open Science Framework. Sample sizes ranged from 22 to 40 participants with a total of 220 participants. Study populations included hand reconstructive surgery (n=70), distal radius fracture (n=53), carpal tunnel syndrome (n=74), hand fractures and tendon injuries (n=23). Five studies had MT interventions that combined MT with active exercises and had comparator groups performing the active exercises for the same duration. MT intervention ranged from 20 to 75 minutes per session and 10 to 30 sessions. Frequency of the interventions ranged from two to five times a week for three to eight weeks. Outcomes were assessed at timepoints between three and 12 weeks. MT interventions reduced pain, improved ROM, strength, and function in most studies, but greater improvements for the MT group than the comparator group were only reported for pain, ROM, and function in a couple studies. Large effect sizes were reported in four

studies, medium in three studies and small in five studies. Risk assessment for the seven included studies resulted in one high quality, four moderate quality, and two low quality studies.

Discussion: The seven studies included in this review are heterogenous in the intervention design, timing of the intervention, population of interest, comparator groups and outcome assessment. MT interventions were effective in reducing pain, ROM, strength, and function for musculoskeletal injuries in the hand/wrist, but caution should be taken with the small sample sizes and risk of bias concerns. MT interventions included components with active movement of the affected extremity which makes it difficult to determine the impact of MT alone. When active movement is available, it is preferred over MT, yet only one study implemented MT during a period of inactivity for the affected extremity.

Conclusion: MT interventions show promise for reducing pain, improving ROM, strength and function for musculoskeletal hand and wrist injuries. Findings should be interpreted with caution given there are some concerns with the risk of bias. Further investigation is warranted with larger trials with more homogenous interventions.

Keywords: musculoskeletal injuries, hand, wrist, mirror therapy, strength, range of motion, pain, function

3.2 Introduction

Mirror therapy (MT) is a therapeutic intervention where a mirror is placed along the midline of the body, so movements are performed with the unaffected extremity in front of the mirror. The mirror generates a reflection of the affected extremity making it appear that it is performing the same movements while it is resting out of sight (1). Observing the reflection in the mirror, where the affected extremity appears unimpaired during movement, is thought to provide therapeutic value by facilitating neuromotor pathways involved in active movement for the affected side in the absence of physical movement (6–9). The literature that has assessed the mechanism of MT has been in healthy populations, while the effectiveness of MT has primarily been investigated in populations with limited ability to actively engage the affected side (e.g. paresis).

MT has been shown to be an effective intervention after a stroke for improving motor function, activities of daily living, reducing pain and motor impairments (13,15). MT has also been applied following an amputation of the extremity and with chronic regional pain syndrome (CRPS). In these conditions MT is thought to initiate cortical reorganization to better integrate sensory feedback for pain free movement (4,5). MT has been shown to be effective at reducing phantom pain, improving function, and reducing pain with CRPS (4,5,17). There are other conditions that have resulting disuse where an intervention like MT may be beneficial.

Musculoskeletal conditions of the extremities could be an appropriate model to investigate the mechanism and effectiveness of MT; specifically musculoskeletal injuries that require immobilization of the extremity to treat the condition/injury. Repercussions of the disuse during immobilization include loss of muscle mass, strength, and neuromuscular function (180). During immobilization there are decreases in corticospinal excitability and other structures that have been implicated in the mechanism for MT (181–183). To determine whether musculoskeletal injuries would be an adequate model to investigate the mechanism of MT it is important to know whether MT is an effective intervention for musculoskeletal injuries. The aim of this systematic review was to investigate the effectiveness of MT interventions for treating pain, strength, ROM, and/or function for musculoskeletal injuries of the hand and wrist.

3.3 Methods

This systematic review was conducted in accordance with Cochrane guidelines and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020. This review was registered with Open Science Framework (DOI:10.17605/OSF.IO/SVF6A).

3.3.1 Eligibility Criteria

The inclusion criteria for this systematic review were:

- Design: randomized controlled trials (RCTs)
- Participants: individuals being treated for a musculoskeletal condition of the hand or wrist
- Interventions: MT
- Comparison: other active treatment or control
- Outcomes: pain, strength, ROM, and function

Studies were excluded if the participants had neurological symptoms impacting the hand or wrist. Studies that were not available in English, protocol papers, reviews, and meta-analyses were also excluded.

3.3.2 Search Strategy and Study Selection

Systematic searches were conducted in EMBASE, Pubmed, and Scopus in April 2024. The search strategy used can be seen in Appendix D. The reference lists of the included studies were searched manually for any additional references. Studies from the electronic searches were imported into Covidence where duplicates were removed. Two independent reviewers (SR and RF) completed a title/abstract screening and full text screen using the eligibility criteria. Any discrepancies in the study selection were resolved by senior author (JCM).

3.3.3 Data Extraction, Analysis, and Quality Assessment

Data extraction was completed by two independent researchers (SR and RF). The data collected from the studies included author, year, study population, sample size, age, sex, mirror therapy protocol, comparison group protocol, session dosage, outcome measures, timeline for follow up, and primary study results. The extracted data from the primary

study results included measures of pain, ROM, strength, and function. Mean and standard deviations were extracted for effect size calculations when available. Hedges' g was calculated and interpreted as a small effect if 0.2 to 0.5, medium effect if 0.5 to 0.8, and large effect if > 0.8 (184). Descriptive synthesis and effect sizes were used to interpret the interventions and outcome findings. If insufficient data was reported, sufficient effort was made to contact the authors via email to request additional data. Risk of bias in the included RCTs was assessed using the Cochrane Risk of Bias tool 2.0 (RoB 2) (185).

3.4 Results

3.4.1 Study Selection

The electronic search provided 787 publications. Duplicates were removed and 407 articles were screened by title and abstract. Full text review was completed for 43 publications and seven studies met the eligibility criteria to be included. The PRISMA flow chart for this selection process is presented in Figure 2.

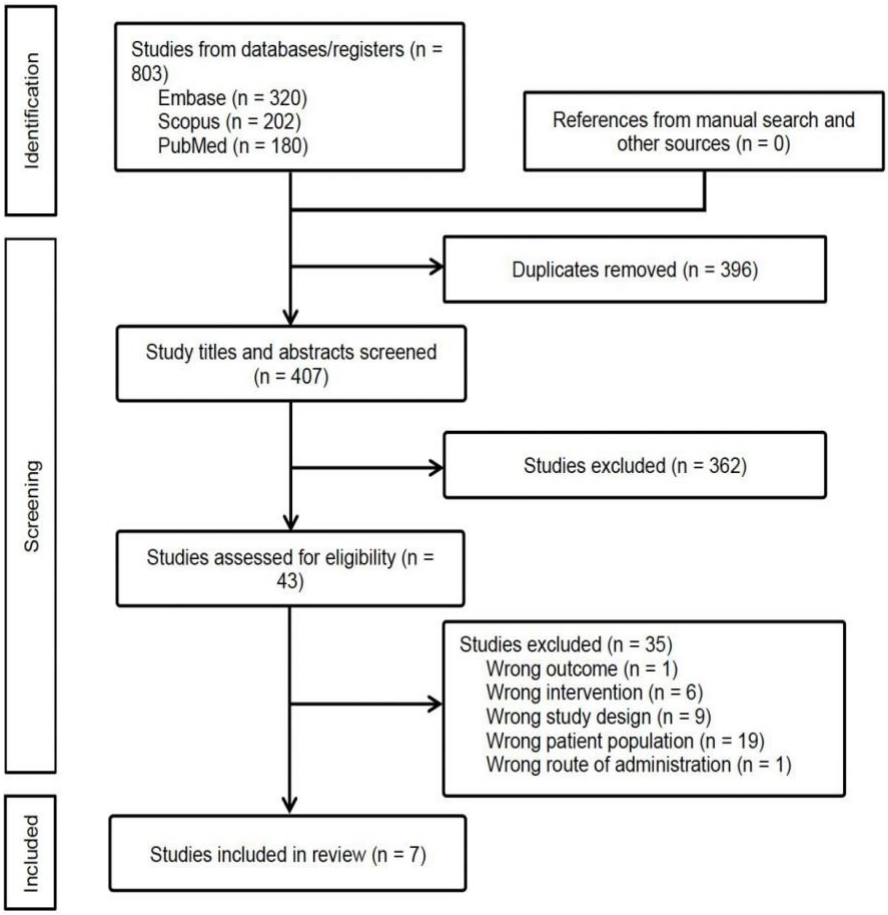

Fig. 2 PRISMA flow diagram.

3.4.2 Study Characteristics

Seven RCTs were included in this review (1,14,184–188). Study characteristics are reported in Table 4. The included studies were published between 2013 and 2023. Four studies investigated MT applications for a single musculoskeletal condition: distal radius fracture (1,186) and carpal tunnel syndrome (14,185). The remaining three studies investigated MT applications with a mixture of hand fractures and tendon injuries (187,188) and musculoskeletal conditions requiring reconstructive hand surgery (184). The number of participants included in the review is 220 with more than half being female (150/220). Sample sizes ranged from 22 to 40 participants.

Table 4. Study details and protocols.

Author	Study Design	Sample Characteristics	Session Dosage	MT Protocol	Comparator Protocol
Abolfazli (2019)	RCT	N=40 patients who underwent reconstructive hand surgery - MT group: 20 (60% male); 30.45 (9.38) y - C group: 20 (65% male); 33.3 (11.46) y	2x/week for 8 weeks = 16 sessions	30 min of standard rehab + 45 min of MT Tasks performed during MT: Purdue pin displacement, resistance exercises, functional exercises. For first 3 weeks performed with unaffected side, the remaining 5 weeks performed with both hands.	75 min of standard rehab
Bayon-Calatayud (2016)	Pilot RCT	N=22 patients treated for distal radius fracture - MT group: 11 (27% male);	5x/week for 3 weeks = 15 sessions	30 min of MT + 30 min conventional	30 min of conventional occupational therapy programme +

		61.09 (13.05) y - C group: 11 (36% male); 55.36 (18.28) y		physiotherapy programme (pain reduction, mobility, and strength training) Tasks performed during MT: Active wrist and finger mobility, grip and grasp training, task-oriented exercises.	30 min conventional physiotherapy programme (pain reduction, mobility, and strength training)
Civi Karaaslan (2020)	RCT	N=35 patients diagnosed with carpal tunnel syndrome (and scheduled for release surgery) - MT group: 18 (6% male); 48.2(9.7) y - C group: 17 (12% male); 53.1 (8.1) y	MT: 5x/week for 2 weeks = 10 sessions Conventional therapy: 10 reps of each exercise, 3x/day for 4 weeks	20 min sessions for first 2 weeks while casted. Then conventional therapy for 4 weeks. Tasks performed during MT: Tendon gliding, ROM, grip, and functional exercises.	2 weeks casted then 4 weeks conventional therapy. Conventional therapy included: water bath (15 min), scar tissue massage, tendon gliding exercises, ROM, and stretching.
Korbus (2022)	RCT	N=31 female patients treated for distal radius fracture - MT group: 12; 75.4 (7.24) y - MP group: 8; 73.1 (6.03) y - C group: 9; 72.4 (6.78) y	5x/week for 3 weeks; 15 sessions in total. Then 3x/week for 3 weeks	45 min sessions: relaxation + MT with unaffected side + usual care Tasks performed	C: Relaxation techniques for same duration as MT and MP + usual care MP: Combination of active movement and

			with independent practice 2x/week.	during MT: palmar flexion, dorsal extension, radial and ulnar abduction, supination, pronation, and squeezing. Exercises were selected based on being difficult to perform.	kinesthetic imagery with and without eyes open
Munoz-Gomez (2023)	RCT	N=39 patients diagnosed with carpal tunnel syndrome - MT group: 20 (20% male); 50.60(11.74) y - C group: 19 (32% male); 57.90 (11.94) y	MT: 5x/week for 6 weeks = 30 sessions	Tasks performed during MT: 10 reps for mobility exercises, 10 reps for tendon and median nerve gliding exercises, 3 sets of 8 reps for strength exercises and 10 reps for functional activities.	Same program as MT but without the mirror (affected hand still under the table).
Rostami (2013)	RCT	N=23 patients with active ROM impairments from tendon injuries or fractures of the hand - MT group: 12	Interventions: 5x/week for 3 weeks = 15 sessions Follow-	Intervention: 30 min MT + 30 min intensive clinical rehabilitation programme + 15 min	Intervention: 30 min observing their hand perform the MT tasks without the mirror + 30 min intensive clinical

		(17% male); 36(22-58) y - C group: 11 (36% male); 39(29-64) y	up period: 3x/week for 3 weeks.	home MT 2x/day Follow Up: Schedule rehabilitation programme	rehabilitation programme + 15 min home action observation 2x/day Follow-up: Scheduled rehabilitation programme
Yalcin (2023)	RCT	N=30 patients treated with surgical repair for hand tendon injuries - MT group: 15 (73% male); 36.07 (14.30) y - C group: 15 (87% male); 38.47(14.84) y	3x/week for 4 weeks = 12 sessions	40 min PT program (whirlpool, US, TENS) + MT Tasks performed during MT: flexor tendon gliding, blocking exercises, ROM, and resistance exercises	40 min PT program + same MT tasks without the mirror

*RCT = randomized controlled trial; MT = mirror therapy, C = comparator, MP = mental practice, y = years of age, min = minutes, reps = repetitions, ROM = range of motion, x/ = times per, US = ultrasound, TENS = transcutaneous electrical stimulation, PT = physical therapy, RoB = risk of bias

The timeline for baseline outcomes varied between studies. One study assessed baseline one day before carpal tunnel release surgery (185) and another one week post-op hand reconstructive surgery (184). Studies that assessed baseline just prior to starting the intervention were on average six to 10 days post-op DRF repair (186), seven to eight weeks since primary repair of tendon injuries or fractures in the hand (187), eleven to twelve weeks since primary repair of tendon injuries in the hand (188), after years of CTS symptoms (14), and the last study did not report the specific time after acute DRF treatment (surgical repair or reduction and immobilization) (1).

3.4.3 Mirror Therapy Parameters

In two studies, MT was the only treatment used in the session. Both studies had MT sessions using only the unaffected upper extremity five times a week for two to six weeks weeks (14,185). Sessions were 20 minutes in duration (185) or based on number of reps and exercises performed (14). Tasks performed in front of the mirror included tendon gliding, ROM, strength and functional exercises (14,185).

In five studies, sessions included the MT intervention and standard rehabilitation (1,184,186–188). Session dosage ranged from two to five times a week for three to eight weeks with a total of 10 to 30 sessions. Duration of the sessions ranged from 45 minutes total (standard rehabilitation and MT) to 30 to 40 minutes of standard rehabilitation plus 30 to 45 minutes of MT. Standard rehabilitation interventions focused on pain reduction with modalities, relaxation techniques, mobility, and strength training (1,184,186–188). Tasks performed in front of the mirror included dexterity, nerve gliding, ROM, strength and functional exercises (1,184,187,188). Parameters and duration of interventions for each study are presented in Table 1. No two studies shared the same intervention design therefore no meta-analysis was completed.

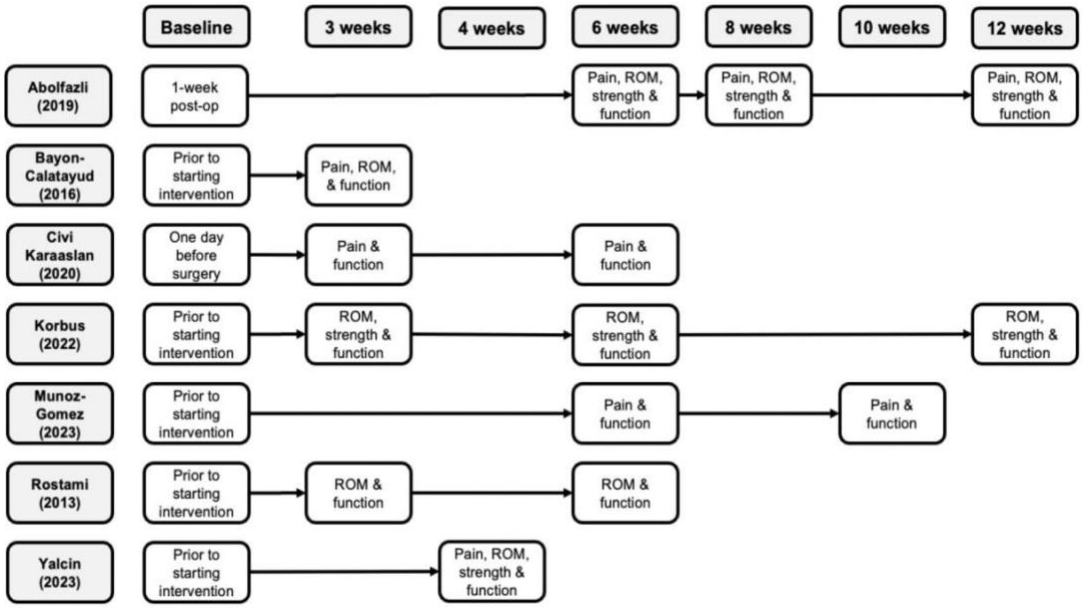

Fig. 3 Overview of outcome measures assessed and timeline.

3.4.4 Outcome Overview

Outcome measures included in the review are pain, strength, ROM, and function. Five studies assessed pain (1,14,184,185,188), three studies assessed strength (184,186,188), four studies assessed ROM (1,186–188), and all seven studies assessed function (1,14,184–188). Figure 3 provides an overview of the outcome measures assessed and assessment timelines for each study.

3.4.5 Pain

The visual analog scale (VAS) was used in four studies (1,14,185,188) and the fifth study used both a pain rating index and number of word count from the McGill pain questionnaire to assess pain (184). Significant group by time interactions were reported in three studies where the MT groups demonstrated greater reductions in pain than the comparator group (184,185,188). In the absence of group by time interactions, main effects for reduced pain were reported for the MT group in two studies assessing pain at the end of the intervention. In these studies the comparator group also reported reduced pain (1,14). Overall improvements in pain ranged from 40% to 87% for the MT groups and 19% to 63% for the comparator groups. Large (184,185), medium (184,185), and small (14,185,188) effect sizes were calculated for pain outcome measures (Table 2). Detailed changes for pain ratings are outlined for each study in Table 5.

Table 5. Study results for pain outcome measures and calculated effect sizes.

Author	Outcome Measures	Effect Size (95% CI)	Pain
Abolfazli (2019)	McGill Pain Questionnaire - pain PRI & pain NWC	PRI: 6W - 1.12 (-1.78 to -0.45), 8W - 1.38 (-2.07 to -0.69), 12W - 1.30 (-1.98 to -0.62) NWC: 6W - 0.74 (-1.38 to -0.10), 8W - 1.27 (-1.95 to -0.59), 12W - 1.32 (-2.01 to	For the MT group, pain PRI scores improved 54%, 62%, and 63% at 6-, 8- and 12- weeks, respectively. For the C group, pain PRI scores improved 25%, 40%, and 59% at 6-, 8- and 12- weeks, respectively. For the MT group, pain NWC scores improved 45%, 74%, and 87% at 6-, 8- and 12- weeks, respectively. For the C group, pain NWC scores improved 26%, 43%, and 63% at 6-, 8- and 12- weeks, respectively. The improvements in pain PRI and NWC scores were

		-0.64)	significantly greater for the MT group than the C group at 6-, 8-, and 12-weeks ($p<0.001$).
Bayon-Calatayud (2016)	Pain VAS		Pain was reduced by 2 for MT and C groups. No group differences were reported.
Civi Karaaslan (2020)	Active, resting and night pain VAS	Rest: 3W 0.92 (0.22 to 1.61), 6W -0.30 (-0.96 to 0.37) Active: 3W 0.25 (-0.41 to 0.92), 6W -0.12 (-0.74 to 0.50) Night: 3W 0.18 (-0.44 to 0.80), 6W -0.82 (-14.6 to -0.17)	The MT group reported less resting and night pain than the control group from 3- to 6-weeks after surgery ($p<0.05$). Resting, activity, and night pain levels were reduced at 6 weeks post op for the MT group ($p<0.05$). Night pain improved for the C group at 3 weeks ($p<0.05$).
Munoz-Gomez (2023)	Minimum, maximum, and average pain VAS	Min: 6W -0.42 (-1.05 to 0.22), 10W -0.40 (-1.04 to 0.23) Max: 6W -0.12 (-0.75 to 0.51), 10W -0.36 (-0.99 to 0.27) Avg: 6W -0.41 (-1.04 to 0.23), 10W -0.28 (-0.91 to 0.35)	MT and TE reported reduced pain at T1, but only maintained at T2 for MT. At T1 maximum pain VAS scores improved 40% and 19% for MT and C groups, respectively ($p<0.05$). Minimum pain VAS scores improved 73% and 56% for MT and C groups, respectively ($p<0.05$). Average pain VAS scores improved 55% and 40% for MT and C groups, respectively ($p<0.05$). Reduced maximum and minimum pain scores ($p<0.05$) were only retained at T2 for the MT group.
Yalcin (2023)	Pain VAS	4W 0.11 (-0.60 to 0.83)	Pain scores improved 67% and 21% for the MT and C groups, respectively ($p<0.05$). The MT group reported greater improvements for pain than the C

			group ($p<0.05$).

*CI = confidence intervals, MT = mirror therapy, C = comparator, VAS = visual analogue scale, PRI = pain rating index, NWC = number of word count, W = week, Min = minimum, Max = maximum, Avg = average

3.4.6 Range of Motion

ROM was assessed in five studies (1,184,186–188). ROM improved for the MT groups in all five studies. A significant group by time interaction was reported with the MT group demonstrating greater improvements in ROM (187). MT groups demonstrated improvements in ROM in two studies, where the comparator group did not demonstrate improvements in ROM (184,188). One study reported improved ROM for all groups (1,186). Large (184,187,188), medium (184), and small (1,186,188) effect sizes were calculated for ROM outcome measures (Table 3). Detailed changes for ROM measurements and effect sizes are outlined for each study in Table 6.

Table 6. Study results for range of motion outcome measures and calculated effect sizes.

Author	Outcome Measures	Effect Size (95% CI)	ROM
Abolfazli (2019)	Active ROM of joint that underwent reconstructive surgery	6W -0.02 (-0.64 to 0.60), 8W 0.24 (-0.39 to 0.86), 12W 0.69 (0.05 to 1.33)	For the MT group, ROM scores improved 20% and 33% at 8- and 12- weeks, respectively ($p<0.001$). No ROM improvements were reported for the C group at 8- and 12-weeks.
Bayon-Calatayud (2016)	Active wrist extension	0.42 (-0.43 to 1.26)	Wrist extension improved 17 degrees for the MT group and 13 degrees for the C group.
Korbus (2022)	ROM_{sum} (palmar flexion + dorsal extension + radial and ulnar	12W -0.34 (-1.21 to 0.53)	ROM_{sum} improved 34, 31, and 44 degrees for MT, MP, and C groups, respectively. The group x time interaction at 12 weeks was not significant ($p=.076$).

	abduction)		
Rostami (2013)	TAM (summative score of all the angles of the joints of the hand while making a fist)	3W 3.31 (2.05 to 4.56), 6W 5.57 (3.76 to 7.37)	For the MT group, TAM scores improved 350% from baseline to 3-weeks and 14% from 3-weeks to 6-weeks. For the C group, TAM scores improved 168% from baseline to 3-weeks and 26% from 3-weeks to 6-weeks. The improvement in TAM scores was significantly greater for the MT group at 3 weeks ($p=0.001$) and 6 weeks ($p<0.05$).
Yalcin (2023)	TAM (summative score of MCP, PIP and DIP ROM) for digits	Digits: 1st -1.38 (-2.17 to -0.58), 2nd 0.10 (-0.61 to 0.82), 3rd 0.16 (-0.56 to 0.87), 4th -0.07 (-0.79 to 0.64), 5th -0.17 (-0.89 to 0.55)	Only the MT group demonstrated improvements in TAM for the 2nd ($p<0.05$), 3rd ($p<0.05$) and 4th digits ($p<0.05$).

* CI = confidence intervals, MT = mirror therapy, C = comparator, MP = mental practice, x = by, ROM =range of motion, TAM = total active motion (normative value is 260 deg), MCP = metacarpophalangeal, PIP = proximal interphalangeal, DIP = distal interphalangeal, W = week

3.4.7 Strength

Lateral pinch strength was assessed in one study (184) and grip strength was assessed in three studies (184,186,188). There were no significant group by time interactions reported for lateral pinch or grip strength in the studies. Lateral pinch strength improved from 8- to 12-weeks after reconstructive hand surgery in the MT, but not the comparator group (184). Grip strength improvements for the MT groups range from 34 to 67% compared to the 28% to 65% in comparator groups (184,186). One study reported no changes in grip strength for either group (188). Large (184), medium (184,188), and small (186) effect sizes were calculated for strength outcome measures (Table 7). Detailed results for strength assessments for each study are presented in Table 7.

Table 7. Study results for strength outcome measures and calculated effect sizes.

Author	Outcome Measures	Effect Size (95% CI)	Strength
Abolfazli (2019)	Grip and lateral pinch strength	Grip: 8W 0.60 (-0.03 to 1.23), 12W 0.58 (-0.06 to 1.21) Pinch: 8W 0.46 (-0.16 to 1.09), 12W 1.01 (0.35 to 1.67)	Grip strength improved 34% for the MT group and 28% for the C group from 8- to 12-weeks ($p<0.001$). Lateral pinch strength improved 13% for the MT group from 8- to 12 weeks and was greater than the C group at 12-weeks ($p<0.05$). Lateral pinch strength did not improve for the C group from 8- to 12 weeks.
Korbus (2022)	Grip strength	Change to 12W: -0.07 (-0.93 to 0.80)	Grip strength improved 67%, 68%, and 65% for MT, MP, and C groups, respectively. The group x time x fracture side interaction at 12 weeks was not significant ($p=.056$).
Yalcin (2023)	Grip strength	4W -0.64 (-1.38 to 0.09)	There were no significant improvements for either group with grip strength.

*CI = confidence intervals, MT = mirror therapy, C = comparator, MP = mental practice, x = by, W = week

3.4.8 Function

Disabilities of Arm, Shoulder and Hand (DASH) questionnaire was used in four studies (14,184,187,188) and the QuickDASH was used in two studies (1,186). Significant group by time interactions for DASH were reported in two studies where the MT groups demonstrated greater improvements in function than the comparator group (184,188). Two studies reported improved DASH scores for both MT and comparator groups after the intervention (14,187). Large effect sizes ranging from -1.13 to -4.10 were calculated for DASH (Table 8). Overall improvements in DASH scores range from 63% to 95% MT and 18% to 66% comparator group (14,184,187,188). The two studies that measured QuickDASH scores reported improved scores for MT and comparator groups over time. No group differences were reported (1,186). Effect sizes for the QuickDASH were small ranging from -0.13 to 0.37 (Table 8).

Table 8. Study results for function outcome measures and calculated effect sizes.

Author	Outcome Measures	Effect Sizes (95% CI)	Function
Abolfazli (2019)	DASH	6W -1.38 (-2.07 to -0.69), 8W -1.67 (-2.40 to -0.95), 12W -1.75 (-2.48 to -1.03)	For the MT group, DASH scores improved 52%, 82%, and 95% at 6-, 8- and 12- weeks, respectively. For the C group, DASH scores improved 25%, 47%, and 66% at 6-, 8- and 12- weeks, respectively. Improvements in DASH scores were greater for the MT group compared to the C group ($p<0.001$).
Bayon-Calatayud (2016)	QuickDASH	Change at 3W: -0.37 (-1.21 to 0.48)	QuickDASH scores improved 25.6 for the MT group and 30.57 for the C group.
Civi Karaaslan (2020)	BCTQ	SSS: 3W 1.69 (0.92 to 2.46), 6W 2.04 (1.22 to 2.86) FSS: 3W 2.55 (1.66 to 3.44), 6W 0.95 (0.25 to 1.65) Total: 3W 0.93 (0.23 to 1.63), 6W 0.54 (-0.14 to 1.21)	There were no significant group x time interactions for BCTQ scores. BCTQ total, FSS, and SSS scores improved at 3- and 6-weeks post op for the MT group ($p<0.05$).
Korbus (2022)	QuickDASH, PRWE	QuickDASH: 12W -0.13 (-1.00 to 0.73) PRWE: 12W -0.42 (-1.29 to 0.45)	The group x time interaction at 12 weeks was not significant ($p=.829$). QuickDASH scores improved 63%, 62%, and 57% for MT, MP, and C groups, respectively. The group x time interaction at 12 weeks was not significant ($p=.946$). PRWE scores improved 74%, 66%, and 57% for MT, MP, and C groups, respectively.
Munoz-Gomez (2023)	DASH, BCTQ		No significant group x time interactions were reported. DASH and BCTQ improved for MT and C at 6-weeks, maintained by both groups at 10-weeks. Both groups

			improved DASH, BCTQ total and BCTQ SSS scores from baseline to 6-weeks ($p<0.001$) and 10-weeks ($p<0.05$). There was no change reported for BCTW FSS scores in the MT group. Only the C group improved their BCTQ FSS scores for the C group improved from baseline to 6-weeks ($p<0.05$) and 10-weeks ($p<0.05$).
Rostami (2013)	DASH	3W -2.09 (-3.11 to -1.08), 6W -4.10 (-5.54 to -2.66)	For the MT group, DASH scores improved 83% from baseline to 3-weeks and 71% from 3-weeks to 6-weeks. For the C group, DASH scores improved 35% from baseline to 3-weeks and 39% from 3-weeks to 6-weeks. DASH scores were significantly greater for the MT group at 3 weeks ($p=0.001$) but not at 6 weeks.
Yalcin (2023)	DASH, PRWE, HFI	DASH: 4W -1.13 (-1.90 to -0.36) PRWE: 4W -0.95 (-1.70 to -0.19) HFI: 4W -0.84 (-1.58 to -0.09)	The MT group reported greater improvements for PRWE and DASH than the C group ($p<0.05$). DASH scores improved by 63% and 18% for the MT and C groups, respectively ($p<0.001$). PRWE scores improved by 60% and 19% for the MT and C groups, respectively ($p<0.05$). HFI scores improved by 58% and 14% for the MT and C groups, respectively ($p<0.001$).

*CI = confidence intervals, MT = mirror therapy, C = comparator, DASH=Disabilities of Arm, Shoulder and Hand questionnaire, PRWE=Patient-Rated Wrist Evaluation, HFI=Hand Function Index, BCTQ= Boston Carpal Tunnel Questionnaire; BCTQ SSS= BCTQ Symptom Severity Scale; BCTQ FSS= BCTQ Functional Status Scale, W = week

The Boston Carpal Tunnel Questionnaire (BCTQ) total score and scores for the Symptom Severity Scale (SSS) and Functional Status Scale (FSS) were assessed in two studies (14,185). No significant group by time interactions for BCTQ scores were reported (14,185). BCTQ total and BSS scores improved for the MT group in both studies (14,185). The FSS scores only improved for the MT group in one study (185). The effect size for SSS and FSS were large ranging from 0.95 to 2.55. The effect size for the BCTQ Total were ranged from medium to large (Table 5). The Patient-Rated Wrist Evaluation (PRWE) was assessed in two studies (186,188). Improvements in PRWE for the MT group ranged from 60 to 74% and 19 to 57% for the comparator group. One study reported greater improvements for the MT group than the comparator group (188). The effect size for PRWE ranged from 0.42 to -0.95 (Table 5). The Hand Function Index (HFI) was assessed in one study which reported greater improvements for the MT group than the comparator group (188). The effect size for the change in HFI scores had a large effect size of -0.84 (Table 5). Detailed results for function assessments for each study are presented in Table 5.

3.4.9 Risk of Bias Assessment

Based on the quality assessment (Figure 4), one study was considered high quality with unclear risk of bias around randomization procedures (186). Four studies were rated as moderate quality with unclear risk of bias for two or more domains. For the moderate quality studies, the concern for bias was due to lack of reporting, leaving uncertainty with deviations from intended inventions and/or selection of the reported result (1,14,185,187). Two studies were rated as low quality due to high risk of bias with lack of blinding or reporting for outcome assessment (184,188). Three of the seven studies were registered in a clinical trials registry (14,184,187). One study had a published protocol (186).

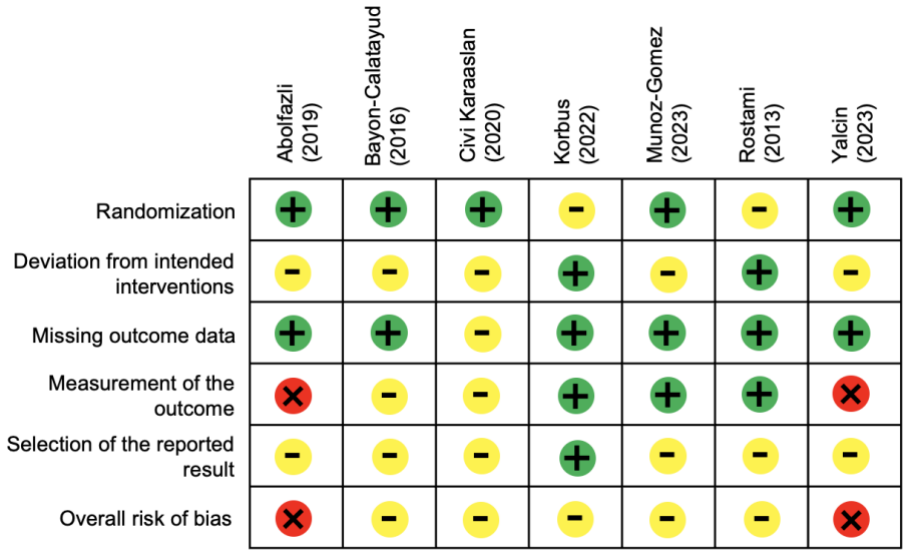

Fig. 4 Risk of bias assessment for each study across the five domains in the Cochrane RoB 2 Tool and overall risk.

3.5 Discussion

This systematic review found that MT interventions are effective for reducing pain, improving strength, ROM, and function following hand tendon injuries and fractures, carpal tunnel syndrome, and distal radius fractures. The MT groups demonstrated improvements that were similar to the comparator groups and in some cases greater. Most of the comparator groups were involved in active interventions (e.g. conventional therapy, action observation); therefore, greater improvements for MT group demonstrates an additional benefit to this type of training over other treatment programs. However, some caution should be taken with the interpretation of the findings due to the concerns highlighted in the risk of bias assessment and small sample sizes. All studies had fewer than 40 participants, but only one was classified as a pilot study. With numerous studies reporting main effects for MT groups, but not the comparator groups in the absence of group by time interactions, this may suggest that the studies did not have sufficient power for the analyses that were conducted.

In five of the included studies the MT intervention included a combination of both MT and conventional treatment approaches. Comparator groups engaged in conventional treatment for a similar duration to the MT intervention without the MT component. For

the MT interventions, there was reduced active practice with the affected side which may explain the greater reduction in the patient reported outcome measures. For example, Abolfazli et al. (2019) had both groups engage in 75 min sessions, but the MT group was only doing active rehabilitation of the affected extremity for 30 min and MT for the other 45 min when the affected extremity could rest. For the comparator group, an additional 45 min of active exercise may have led to overuse of the affected extremity which could explain greater reported pain and less of an improvement in function for the comparator group. Another subjective measure that would have been helpful for explaining potential group differences is the motor imagery ability of the participants included. Ratings of motor imagery ability is moderately correlated with changes in corticospinal excitability when observing the reflection during MT (189). Vividness of motor imagery was only measured in one of the included studies where groups were randomized by motor imagery ability (186). It is important that future studies assess how well participants can engage in motor imagery so more detailed interpretations can be made for the results.

For objective measures, group differences for grip strength were not reported in any study. Two studies reported improvements in grip strength for both the MT and comparator groups, but participants in both groups performed active strengthening exercises with the affected extremity as part of their interventions (184,186). The only study that reported no improvements in grip strength for the MT or comparator group did not appear to engage in strengthening exercises with the affected extremity during the conventional therapy component of their intervention (188). Where lateral pinch strength was reported to improve, there was also an active strengthening component to the MT intervention with the affected side (184). The methods for measuring ROM were more variable than grip strength across the studies. Three of the studies assessed different summative scores for ROM and with multiple types of hand injuries (186–188). Subgroup analyses were not completed in the studies including multiple *musculoskeletal* conditions to determine the impact that injury type had on ROM or any other measure (187,188). The two studies that only assessed DRFs found similar improvements in ROM for the MT and comparator groups, but that is to be expected with both interventions incorporating active ROM exercises with the affected wrist (1,186). Unfortunately, the other two studies looking at a single condition did not

measure ROM (14,185). With the studies that assessed strength and ROM incorporating active training of the affected extremity in the MT and comparator interventions, it is hard to differentiate the effect that MT would have alone. Muñoz-Gómez et al. (2023) had the comparator group engage in action observation while performing the same exercises as the MT group but without the mirror. Performing movements on the unaffected side can lead to cross education on the affected side, while strength training on one side can lead to 28% to 48% strength gains and increases in corticospinal excitability on the untrained side (190). Action observation is another motor imagery technique that also modulates corticospinal excitability (191). Therefore, practicing the same exercises with the unaffected side and observing the movements can also increase cortical activation, as with MT. This may be why reports of function were similar between these groups. However, pain was reduced more for the MT group which demonstrates that the reflection of the affected hand is an important part of the mechanism to reducing pain.

Civi Karaaslan et al. (2020) was the only study to investigate a MT intervention with no active component to the intervention and no active comparator group because the MT intervention was done during the two-week casting period after surgery for CTS. Pain was reduced and function was improved with the MT but not the comparator group. Even after four weeks of the same conventional therapy in both groups, the MT group still reported reduced pain which could be due to two additional weeks of rehabilitation provided during the immobilization period with the MT intervention. By applying MT during immobilization, when active movement is unavailable in the affected extremity, it can reduce the amount of disuse for the neuromotor pathways during immobilization and allows rehabilitation programs to start earlier and take a more preventative approach. With only two weeks of immobilization after surgery for CTS, there may be better models to investigate MT interventions where immobilization is required for three or more weeks, which is comparable to the intervention duration for six of the seven studies included. One example is DRFs which are commonly immobilized for six weeks where the disuse can have substantial impacts on pain, ROM, strength, and function (113,115). MT may be an option for mitigating the resulting impairments from immobilization by being a passive modality for the affected side when active movement is not available.

When active movement is available, it is preferred over a more passive modality. Activation of the pathways during MT is increased even with the addition of passive movement of the affected extremity (192); therefore, active movement, with or without MT, would lead to even greater activation of the neuromotor structures. For all of the studies that used MT and conventional therapy, recovery of the injury would have needed to be far enough along to allow for active movement of the affected extremity. Application of MT at this time in recovery may not be as beneficial when other options with greater activation of the pathways are available.

Some limitations of this systematic review are only seven studies included all with some concerns for bias or high risk of bias. The concerns with risk of bias were mostly from lack of reporting and/or outcome assessment that was not blinded. The diverse methods used in each study did not allow for statistical synthesis of results or a meta-analysis of the data. Therefore, more research is needed with high quality studies using isolated MT interventions applied to a single condition and more standardized outcome assessments would be encouraged. This systematic review provides sufficient evidence for the effectiveness of MT for reducing pain, improving ROM, strength, and function for musculoskeletal wrist and hand conditions to warrant further investigation with larger studies. It would be interesting for future studies to investigate the effects of MT during immobilization for three or more weeks in the absence of active movement, to determine the effectiveness of MT on outcomes following musculoskeletal hand/wrist injuries. The studies should assess patient reported outcome measures, including motor imagery abilities, and objective outcomes like strength and ROM.

3.6 Conclusion

MT interventions for the musculoskeletal injuries in the hand/wrist demonstrate reductions in pain by 21 to 25%, improvements in strength by 2 to 6%, and function by 29 to 45% more than the comparator groups. Findings should be interpreted with caution given there are some concerns with the risk of bias. Only one study capitalized on the application of MT during immobilization which warrants further investigation. The included studies have small sample sizes and concern for risk of bias so caution should be taken with interpretation of the results. Further investigations with larger trials

using more standardized MT interventions, timing of the intervention, comparator groups, and outcome assessments should be used to allow for more direct comparisons of MT.

4 The feasibility of in-home mirror therapy and neuromuscular electrical stimulation interventions during immobilization of distal radius fractures: Quantitative assessment

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4.1 Abstract

Introduction: Neuromuscular electrical stimulation (NMES) and mirror therapy (MT) can be applied at home during immobilization for distal radius fractures (DRF) as a preventative strategy in attempt to mitigate the resulting impairments from disuse during immobilization. The aim of this study is to determine the feasibility of in home MT, NMES, and MT+NMES interventions during immobilization for DRF.

Methods: Participants were recruited from the Roth| McFarlane Hand and Upper Limb Centre (HULC) in London, Ontario, Canada if they had sustained a DRF in the last three weeks, being managed conservatively, 18–80 years old, able to understand instructions in English, and able to provide informed consent. Individuals were excluded if there was a presence of cognitive disorders and visual impairments that would limit the ability of the individual to follow instructions and engage in the home interventions, superficial metal implants in the injured arm, active cancer, severe peripheral vascular disease, or thrombophlebitis in the injured arm. Three weeks post-DRF participants were randomized to the MT, NMES, MT+NMES, or control group. Intervention groups performed the interventions in-home for 10 minutes, three times a day, 5 days a week for the last three weeks of immobilization. Feasibility was assessed with recruitment rate, adherence to the home interventions, retention to follow up, and limited efficacy testing. The threshold to proceed to a full RCT is 6 to 7 participants recruited on average per month, adherence to in-home interventions >80% and retention to on-site visits of >80%. Outcome assessments included measurement of pain, function, range of motion, dexterity, grip, and pinch strength at initial visit (3 weeks), 6-, 8-, and 12-weeks post-DRF. The threshold for the limited efficacy testing was within group improvements from initial to 12-week post-DRF visits that exceed the minimal clinically important difference (MCID).

Results: This interim analysis reports on 19 participants between 22 and 78 years of age (mean = 58 ± 14.3). An average recruitment rate of 5 participants per month and 75% retention to follow up for the control group are in the amber zone indicating

proceed with changes. The adherence to interventions, retention for on-site visits, limited efficacy testing are in the green zone to proceed with the trial.

Discussion: Based on the interim results for this feasibility RCT the recruitment rate, adherence to the in-home MT, NMES, and MT+NMES interventions, retention to on site visits, and limited efficacy testing show promise for the feasibility of these interventions but may require changes to the recruitment strategy and follow up for the control group if the existing trends proceed as the full feasibility sample is collected.

Conclusion: The full feasibility sample size is required before decisions can be made about whether a full RCT is warranted.

Keywords: mirror therapy, neuromuscular electrical stimulation, early intervention, distal radius fracture, function, pain, strength

4.2 Introduction

One of the most common fractures in adults are distal radius fractures (DRFs) with a female to male incidence ratio of 3.4 to 1 (89,193). Management for DRFs includes surgery or reduction and immobilization via a cast for six weeks. The disuse of the wrist during the immobilization period make the extremity susceptible to muscle atrophy, pain, reductions in function, range of motion (ROM), dexterity, and grip strength (113,115,180). During disuse conditions, females are more susceptible to muscle loss, reduced strength, and a slower recovery (194). Once the cast is removed, patients require three to six months of physiotherapy to restore ROM, strength, and function with some patients reporting persistent impairments over a year after fracture (113,115,118,178). Finding a way to allow for bone healing, but still activate pathways involved in movement may be advantageous during the immobilization period to mitigate the resulting impairments from disuse. Starting treatment during immobilization allows for rehabilitation of neuromotor pathways to start earlier while the bone is still healing. Application of mirror therapy (MT) and/or neuromuscular electrical stimulation (NMES) during immobilization could potentially maintain these pathways and mitigate the resulting impairments seen after the cast is removed.

MT and NMES activate different aspects of the neuromotor pathway used in active movement without moving the extremity. NMES application provides local activation of the muscles while MT activates cortical networks (6–9,25,28–30,146). Using MT combined with NMES is proposed to increase cortical activation and provide afferent input simultaneously to mimic voluntary movements better (195–197). DRFs are a good model for assessing MT and NMES interventions during the casting period due to the six weeks of immobilization, the increased incidence in females, and greater negative impacts of disuse for females (89,193,194). MT and NMES interventions can be performed in-home. The aim of this feasibility randomised controlled trial (RCT) was to determine if MT, NMES, and MT+NMES interventions can be performed in-home during immobilization for DRFs with on-site outcome assessments at 3-, 6-, 8- and 12-weeks post-DRF.

Specifically, recruitment rate, adherence to intervention, retention to on-site visits, limited efficacy testing were assessed. Practicality and acceptance were assessed in a separate study (see Chapter 5).

4.3 Methods

This is a single-blinded, feasibility RCT with four groups. All four groups engaged in standard of care (SoC) during immobilization for DRF. The control group (d) did not participate in any other interventions. The intervention groups participated in (a) MT, (b) NMES, or (c) MT+NMES in addition to SoC. Participants were recruited from the Roth| McFarlane Hand and Upper Limb Centre (HULC) in London, Ontario, Canada. The trial has ethics approval from the Human Research Ethics Board at the University of Western Ontario and was registered with ClinicalTrials.gov (NCT05925673) (Appendix F). Upon providing informed consent to participate, participants were allocated to a group consecutively with sealed, opaque envelopes. The allocation order was prepared using web-based randomisation software by a third party. A block size of four was used. Allocation was stratified by sex. The study was single blinded, with participants aware of group assignments and outcome assessors blinded. All outcome assessments were conducted in the same fashion for all groups.

4.3.1 Recruitment

To be eligible for the study, individuals needed to have sustained a DRF in the last three weeks that is being managed non-operatively at HULC. Additional inclusion criteria were 18–80 years old, able to understand instructions in English, and able to provide informed consent. Additionally, the individual could not have any of the following exclusion criteria: presence of cognitive disorders and visual impairments that would limit the ability of the individual to follow instructions and engage in the home interventions, superficial metal implants in the injured arm, active cancer, severe peripheral vascular disease, or thrombophlebitis in the injured arm.

4.3.2 Interventions

Interventions were performed for 10-minute sessions, three times a day, five days a week for the last three weeks of the casting period. All three interventions groups engaged in SoC plus their respective interventions during the immobilization period. SoC during immobilization of DRF involves elevating the extremity, ROM exercises for the fingers, thumb, and elbow. Following the removal of the cast, SoC is to start ROM exercises right away and add in strengthening exercises approximately 8 weeks post-DRF. The control group engaged in SoC alone.

The NMES intervention was applied with an Intensity Twin Stim III set to EMS, alternating, pulse duration of 300 μs, pulse frequency of 50 Hz, ramp up one sec., contract two sec., and ramp down one sec. With the device set to alternating, the stimulation alternated between the wrist flexors and wrist extensors. Two 1.25" round electrodes were placed proximal to the cast edge over the wrist flexors and another two over the wrist extensors. Optimal electrode placement was selected when the participant could feel the stimulation extending distally along the wrist flexors and extensors. Permanent marker was used to mark the cast to note electrode placement and/or a picture was taken with the participants phone to use during the set up in their homes. Participants were instructed to set the intensity to the highest intensity tolerable where participants could feel the stimulation without any wrist movement or pain.

The MT intervention was applied using a 16" x 20" mirror and a tabletop easel were. Participants were instructed to set up the mirror so it was along the midline of their body where they could not see the affected arm and saw the reflection of the unaffected arm in the mirror. Participants performed 10 repetitions (reps) of each of the following exercises: making a fist and extending the fingers, wrist flexion and extension, ulnar and radial deviation of the wrist, and pronation/supination (Appendix G). Participants also performed six wrist circles in one direction and another six circles in the other direction. These 5 exercises were repeated two times for the 10-minute session. With this timing, each rep should take six seconds so

participants were encouraged to watch the reflection and try to imagine/feel the movement in the affected arm, while it remained relaxed.

The same materials and instructions were provided to the MT+NMES intervention group, but participants performed the interventions concurrently. While the affected arm is relaxed and out of sight for the MT, the NMES device would stimulate the wrist flexors and extensors. Participants were encouraged to match the six second timing of the exercises and stimulation together with increased activation of the muscle group involved. For example, participants paired the wrist flexion movement with wrist flexor stimulation and then moved into wrist extension as the stimulation moved to the wrist extensors.

4.3.3 On-Site Visits

Participants attended HULC for four sessions at 3-, 6-, 8-, and 12-weeks post-DRF. At the initial visit (3-weeks post-DRF), participants completed questionnaires, baseline measures for the unaffected extremity, were randomized to a group. During the initial session, individuals randomized to an intervention group were taught how to perform the intervention at home, supplied with the materials for the intervention, an instructional booklet, and session tracker. The 6-week follow up visit happened the day the participants' cast was removed. At this visit the intervention package was returned, questionnaires were completed, measures were repeated for the unaffected extremity, ROM and dexterity were measured for the affected extremity. At this point participants started rehabilitation either with the HULC team or at the location of their choosing, but the rehabilitation program was not followed for the study. The next follow up visit was scheduled from eight to 10 weeks post-DRF. Questionnaires and previous measures were repeated. Strength was assessed on the affected side for the first time. The final visit was 12-weeks post-DRF to repeat questionnaires and outcome measures. Figure 5 outlines the study timeline from recruitment to outcome assessment.

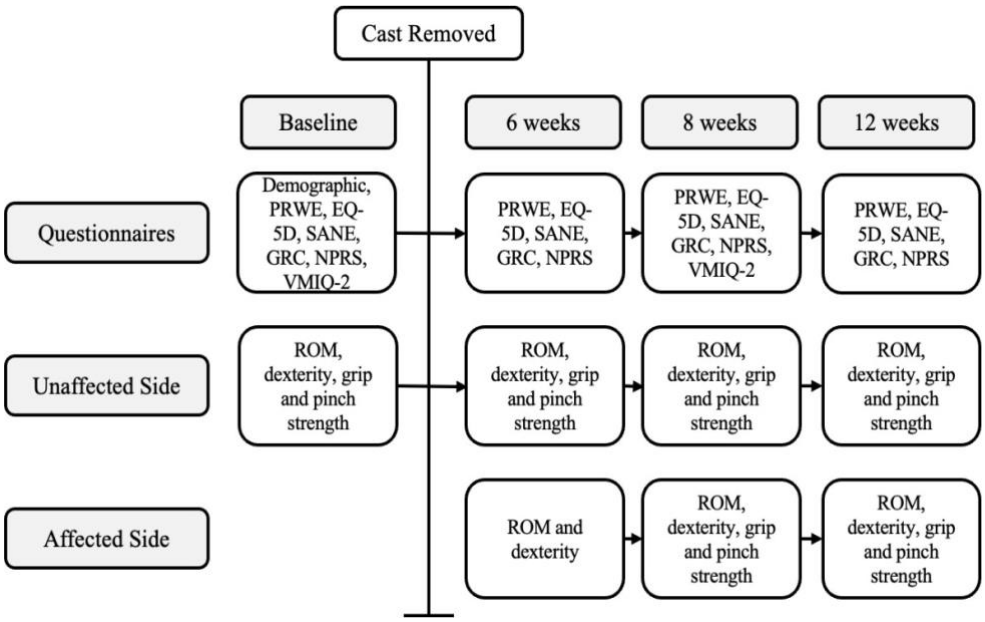

Fig. 5 Study timeline for outcome assessment.

4.3.4 Outcomes

The Patient-Rated Wrist Evaluation (PRWE), EuroQol-5D (EQ-5D), Single Assessment Numeric Evaluation (SANE), Global Rating of Change (GRC), and Numeric Pain Rating Scale (NPRS) at rest and during movement were assessed at each site visit. The questionnaire booklet is presented in Appendix H. The Vividness of Movement Imagery Questionnaire-2 (VMIQ-2) was assessed at the initial visit and the 8-week visit. ROM, dexterity, grip, and pinch strength were measured at each visit for the unaffected side. For the affected side, ROM and dexterity were measured at the 6-, 8-, and 12-week visits. Grip and pinch strength were measured on the affected side at the 8- and 12-week visits.

4.3.4.1 Objective Measures

Grip strength was measured using a Jamar Hydraulic Hand Dynamometer and pinch strength was measured with a Baseline Pinch Gauge. Grip and pinch scores were calculated to be the average of three maximal voluntary contractions (MVCs) for each. Participants were seated with their arm by their side, elbow at 90 degrees and wrist in a neutral position during measurement. The Jamar Dynamometer is a reliable measure and is regarded as the gold standard for grip strength assessment

(198). The minimal clinically important difference (MCID) for grip strength after DRF is 6.5 kilograms or 19.5% relative to the unaffected side (199).

Dexterity was measured using the Purdue Pegboard Test (PPT). Participants completed the single hand, both hands, and assembly subtests on each side once their cast was removed. The PPT is a valid and reliable measure of dexterity following hand injuries (200,201). There is limited literature on the MCID for the PPT, but minimal detectable change (MDC) values are reported around 3 for single hand and both hands while assessmbly conditions 8.5 is reported in populations with schizophrenia (202). The only dexterity measure assessed at the initial visit was the single hand subtest using the unaffected side.

ROM measures included wrist flexion and extension, ulnar and radial deviation, supination, pronation, and thumb extension/radial abduction. Participants were seated with their arm adducted to the side of their body and extended forward onto the table. The participants fingers were extended and adducted for wrist flexion, extension, ulnar and radial deviation. The ulnar side of the hand placed on the table for wrist flexion and extension measurements. The same position was used for measuring thumb extension. For ulnar and radial deviation, the participants palm was one the table and participants were instructed to keep their fingers touching the table. At the initial visit, the ROM measures were only collected on the unaffected side, due to the cast on the affected side.

4.3.4.2 Patient Reported Outcome Measures

PRWE was used to assess pain and function. The PRWE asked participants to rate their average pain and difficulty they had with their wrist during various activities in the past week. For the pain section, participants used a scale from 0 meaning “no pain” to 10 meaning “the worst pain you have ever experienced or that you could not do the activity because of pain”. For the function section, participants used a scale from 0 meaning “no difficulty” to 10 meaning “so difficult you were unable to do it at all”. The maximum score for pain is 50 and function is 50. The highest total score possible is 100, with higher ratings indicating worse pain and function. PRWE

is a valid, reliable and responsive measure to use with DRF populations (203). The MCID for PRWE after DRF is 11.5 points (204).

The NPRS was also used to assess pain. The MCID for NPRS ratings for musculoskeletal conditions is 2 points or 33% (205). NPRS has moderate construct validity and excellent test-rest reliability for populations with musculoskeletal wrist conditions (206). Participants rated their pain at rest and during movement using the NPRS where 0 means “no pain”, 5 is “moderate pain” and 10 is “unbearable pain”. Participants were asked to consider their average pain for each during the past week when providing a response. SANE was also used to measure function. SANE is responsive measure for the upper extremity with a MCID of 15% reported (207). The SANE was used to provide and overall rating of their wrist today by asking “On a scale from 0 to 100, how would you rate your wrist today (with 100 being normal)?” (208).

The EQ-5D was used to assess health status. The EQ-5D demonstrates good validity and reliability across patient populations and is a responsive measure following DRF (209). An MCID for the EQ-5D visual analog scale is reported to be 12 points in musculoskeletal populations (210). Participants were asked to select one box best describing their mobility, usual activities, self-care, pain/discomfort, and anxiety/depression today. Options included no problems, slight problems, moderate problems, severe problems, extreme problems or unable to do. Participants then provided a rating of their health on a scale from 0 “the WORST health you can imagine” to 100 “the BEST health you can imagine”. The GRC scale was used to assess their overall condition of their wrist from the time of treatment until now. The scale provided was from -5 meaning “very much worse”, 0 “being unchanged”, to 5 “completely recovered” (211). In considering their ratings for GRC, participants were asked to consider the start of treatment as when they had their cast put on.

With the VMIQ-2 participants are asked to rate 12 different activities from three perspectives: external visual imagery, internal visual imagery, and kinaesthetic imagery. The VMIQ-2 demonstrates validity as a visual and kinaesthetic measure in

athletic populations (212). In external imagery participants are encouraged to think about the activities as if they are watching themselves performing the movement for an external viewpoint. In the internal imagery they are instructed to visualize the activity "looking out through your own eyes whilst performing the movement". For kinaesthetic imagery, they are instructed to imagine "feeling yourself do the movement". Ratings are provided from 1 "perfectly clear and as vivid (as normal vision or feel of movement)" to 5 "no image at all, you only 'know' that you are thinking of the skill". The highest score for each condition is 60, with a total score of 180. Higher scores represent reduced ability to imagine.

4.3.5 Statistical analysis

A sample size of 72 participants with 18 participants in each group was selected for this study. This was determined based on recommendations for 10 to 15 participants per group with a medium (0.5) to large (0.8) effect size (213) and considering an effect size of 0.84 for grip strength with individuals that participated in home programs after DRF (214). A conservative estimate was taken to select 15 participants, plus a 20% buffer with consideration of study withdrawals and/or loss to follow up. The mean within-group difference with 80% confidence intervals (CI) from the initial visit to the 12-week visit are reported in tables for each group. Means are visually presented in Figures. For the objective measures, we needed to see evidence of within-group change over time to retain the outcome for the full study. We recorded any issues with practicality.

Thresholds for recruitment, adherence to intervention, and retention are presented in Table 9. The recruitment rate was based off a target feasibility sample size of 72 participants recruited in one year. The threshold for the limited efficacy testing was the MCID contained within the 80% CI of the within-group mean differences.

Table 9. Feasibility thresholds for recruitment, adherence, and retention.

Feasibility Outcome	Green Zone	Amber Zone		Red Zone
	Proceed	**Proceed with changes**	**Cut-off**	**Do not proceed**
Recruitment (avg/month)	6 to 7	4 to 5	3	<3
Adherence	>80%	50 to 80%	<50%	<30%
Retention	>80%	50 to 80%	<50%	<30%

4.4 Results

4.4.1 Recruitment

The flow for recruitment and enrolment can be seen in Figure 6. Recruitment took place between January and April 2024 with 19 participants randomly assigned to a group for an average of 5 participants recruited per month. A total of 125 patients were screened, 33 patients were eligible to participate, and 20 consented to participate (Figure 6). Patients that were not interested in participating disclosed, without prompt, that they were not interested due to living out of town and having challenges with transportation. One individual consented to participate but became ineligible due to pursuing surgical management prior to randomization. The recruitment rate was within the amber zone indicating proceed with changes.

Nineteen participants enrolled in the study and were randomized to a group. The age of the participants ranges between 22 and 78 years of age (mean = 58 ± 14.3). All the participants were right hand dominant. Nine participants fractured their dominant hand, and ten participants fractured their non-dominant hand. Group demographics and attendance to on-site visits are reported in Table 10.

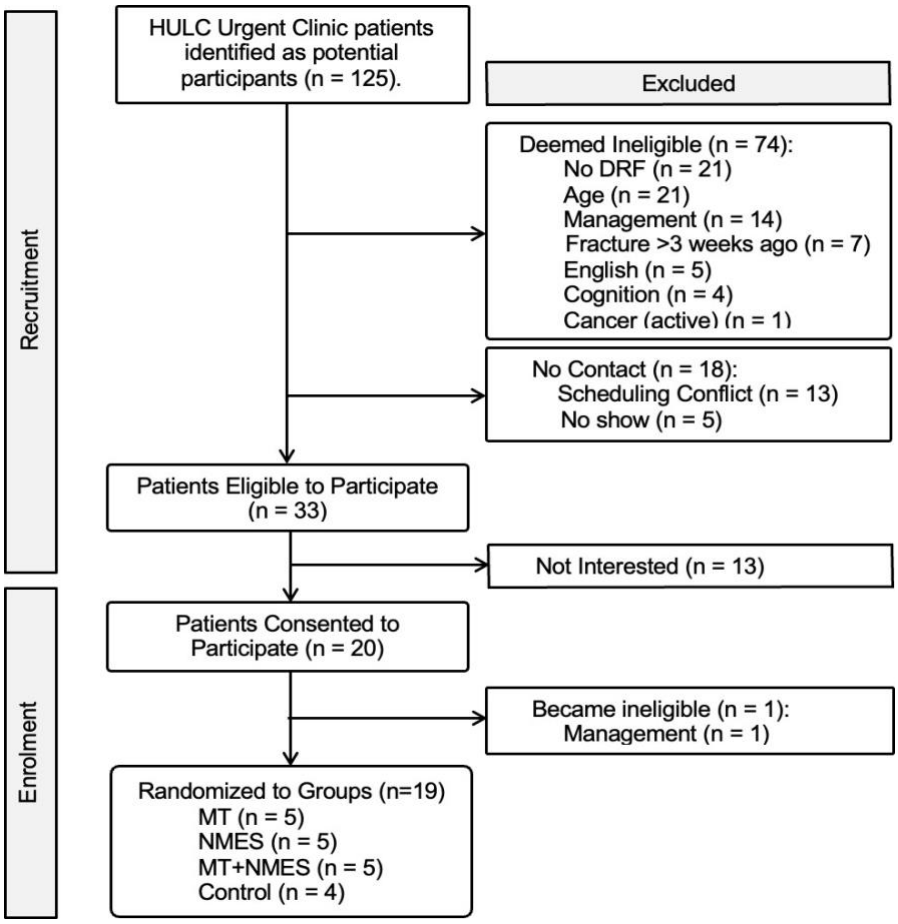

Fig. 6 Flow diagram for recruitment and enrolment.

4.4.2 Adherence to the Intervention

The completion rate for the 45 sessions for the interventions was 89%, 100%, and 96% for the MT, NMES, and MT+NMES groups, respectively. Adherence to the interventions for each group exceeds the >80% threshold for the green zone to proceed with the trial. Means and standard deviations are reported in Table 10. There were no adverse events during the in-home interventions.

Initial visits were scheduled 11 to 23 days since fracture. The visit scheduled for 11 days post-fracture was due to the participants schedule, but the intervention did not start until 21 days post- fracture. The six week follow up visits ranged from 35 to 53 days post-fracture. The eight week follow up visits ranged from 44 to 71 days post-fracture. The twelve week follow up visits ranged from 75 to 95 days post-fracture. The number of days since fracture are reported by group in Table 10. The variability in scheduling

for follow up visits was primarily due to linking research visits with appointments that the participants had scheduled at the clinic.

Table 10. Group demographics.

	MT (n = 5)	**NMES (n = 5)**	**MT+NMES (n = 5)**	**Control (n = 4)**
Age (Mean ± SD)	64 ± 14.5	60 ± 8.9	47 ± 19.6	63 ± 4.9
Sex (M / F)	1 / 4	1 / 4	1 / 4	0 / 4
Injured Side (L / R): % Dominant	3 / 2 40%	2 / 3 60%	3 / 2 40%	2 / 2 50%
Days Since Fracture: Initial Visit 6 Week Visit 8 Week Visit 12 Week Visit	 21 ± 1.2 41 ± 4.5 61 ± 6.8 87 ± 2.6	 20 ± 1.3 43 ± 3.2 60 ± 3.1 85 ± 5.0	 19 ± 4.3 43 ± 6.6 57 ± 2.2 81 ± 6.1	 21 ± 0.6 41 ± 1.7 62 ± 6.5 83 ± 1.4
Employment Status (n): Going to Work Working from Home Temporary Leave Homemaker Retired	 - - 1 1 3	 1 1 - - 3	 - 1 1 1 2	 1 - - - 3
VMIQ-2: External Visual Imagery Internval Visual Imagery Kinaesthetic Imagery	 33 ± 14.9 31 ± 14.3 26 ± 16.8	 28 ± 12.4 29 ± 10.8 29 ± 14.3	 23 ± 15.4 20 ± 9.6 30 ± 19.3	 30 ± 21.2 29 ± 21.5 21 ± 8
Sessions Completed:	40 ± 7.6	45 ± 0	43 ± 4.0	N/A
Attendance to Visits: Initial Visit 6 Week Visit 8 Week Visit 12 Week Visit	 5 5 5 4	 5 5 5 4	 5 5 4 4	 4 3 3 3

SD = standard deviation, M = male, F = female, MT = mirror therapy, NMES = neuromuscular electrical stimulation, n = sample, VMIQ-2 = The Vividness of Movement Imagery Questionnaire-2

4.4.3 Retention for On-Site Visits

Attendance to the on-site visits was 100% in the MT and NMES groups, 93% for the MT+NMES group, and 75% for the control group. Adherence to the interventions

for each group exceeds the >80% threshold for the green zone to proceed with the trial for the intervention groups. The 75% retention to follow up visits for the control group falls within the amber zone to proceed with changes. The number of participants that attended each session for each group is presented in Table 10.

Data collection is ongoing, but all data has been collected for the 19 participants. There were four participants that did not complete all four on-site visits. One participant in the NMES group missed the 12-week visit due to travel that was disclosed prior to randomization. After the initial session, one participant in the control group was withdrew from the study without disclosing the reason. One participant in the MT+NMES group was stopped participating in the study after the 6-week visit due to moving out of town and this was the case for another individual in the MT after the 8-week visit. There was no difference in attendance to on-site visits whether there was a clinic appointment preceding the research visit or not. The session attendance was 19/19 for the initial (3-week), 18/19 for the 6-week, 18/19 for the 8-week, and 15/19 for the 12-week visits.

Participants that attended appointments at HULC prior to outcome assessment for the initial visit was 1/5 for MT, 3/5 for NMES, 3/5 for MT+NMES, and 0/4 for the control group. All participants had appointments with the surgeons where their casts were removed prior to the 6-week outcome assessment. The 8-week outcome assessment was preceeded by an appointment at HULC for 2/5 for MT, 5/5 for NMES, 1/4 for MT+NMES, and 2/3 for the control group. The 12-week outcome assessment was preceeded by an appointment at HULC for 1/4 for MT, 4/4 for NMES, 2/4 for MT+NMES, and 1/3 for the control group. There were no adverse events during outcome assessment.

4.4.4 Limited Efficacy Testing

4.4.4.1 Objective Outcome Measures

Mean grip and pinch strength, and ROM are reported as a percentage of the unaffected side in Figures 7 and 8. Grip strength is the primary objective outcome measure of

interest. Within group mean differenced from the initial visit to 12-week follow up are reported.

The mean difference for grip strength in the MT group was -16.8 (SD = 15.3, 80% CI [-29.28, -4.22]). The mean difference for grip strength in the NMES group was –6.0 (SD = 34.7, 80% CI [-34.44, 22.44]). The mean difference for grip strength in the MT+NMES group was -22.0 (SD = 14.9, 80% CI [-34.16, -9.84]). The mean difference for grip strength in the control group was -24.3 (SD = 13.7, 80% CI [-39.19, -9.47]). Mean grip and pinch strength are reported as a percentage of the unaffected side in Figure 7.

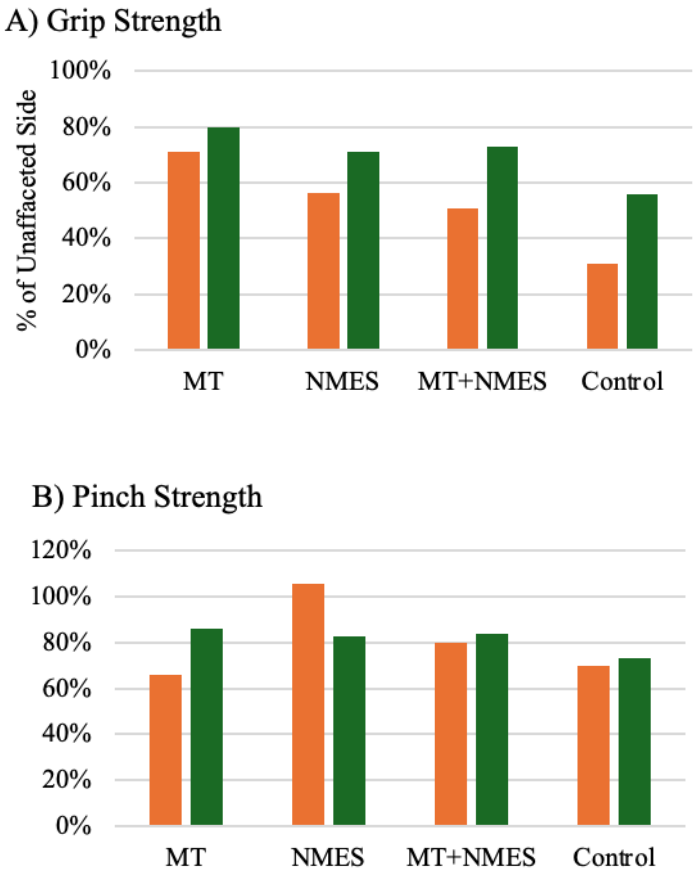

Fig. 7 Group measures for grip (A) and pinch (B) strength as a percentage of the unaffected side at eight (orange) and 12-weeks (grey).

The mean difference for pinch strength in the MT group was -3.3 (SD = 20.0, 80% CI [-19.61, 13.11]). The mean difference for pinch strength in the NMES group was 34.8 (SD = 118.0, 80% CI [-61.92, 131.42]). The mean difference for pinch strength in the MT+NMES group was -3.3 (SD = 11.4, 80% CI [-12.62, 6.12]). The mean difference for pinch strength in the control group was -3.0 (SD = 26.9, 80% CI [-32.29, 26.29]).

The mean difference for PPT single in the MT group was -9.5 (SD = 26.7, 80% CI [-31.34, 12.34]). The mean difference for PPT single in the NMES group was -6.3 (SD = 31.9, 80% CI [-41.06, 28.39]). The mean difference for PPT single in the MT+NMES group was -33.3 (SD = 31.5, 80% CI [-59.05, -7.45]). The mean difference for PPT single in the control group was -9.7 (SD = 12.4, 80% CI [-23.19, 3.86]). The mean difference for PPT assembly in the MT group was -13.3 (SD = 15.1, 80% CI [-25.62, -0.88]). The mean difference for PPT assembly in the NMES group was -13.3 (SD = 48.4, 80% CI [-66.02, 39.36]). The mean difference for PPT assembly in the MT+NMES group was 2.5 (SD = 4.9, 80% CI [-1.54, 6.54]). The mean difference for PPT assembly in the control group was -18.7 (SD = 16.5, 80% CI [-36.63, -0.70]).

The mean difference from the initial visit to the 12-week visit , 80% CI, and standard deviation for each group are documented in Appendix I. Mean values for wrist flexion, extension, ulnar deviation, radial deviation, supination, pronation, and thumb extension at 6-, 8- and 12-week visits are are reported as a percentage of the unaffected side in Figure 8.

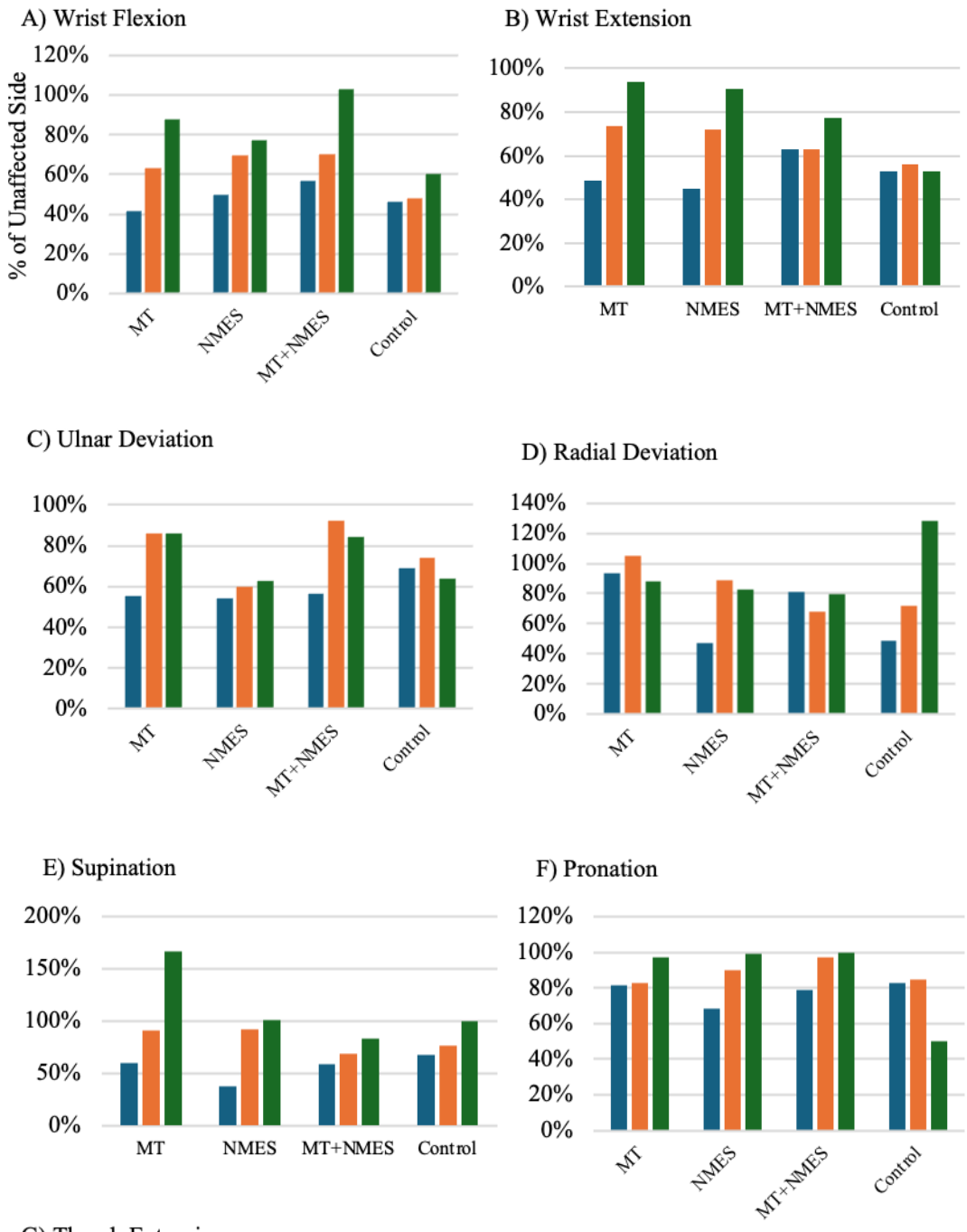

Fig. 8 ROM relative to the unaffected side for A) wrist flexion, B) wrist extension, C) ulnar deviation, D) radial deviation, E) supination, F) pronation, and G) thumb extension at 6- (blue), 8- (orange), and 12-week (grey) visits.

4.4.4.2 Patient Reported Outcome Measures

Patient reported outcome measures were assessed at the initial visit, 6-week, 8-week, and 12-week follow up visit. Within group mean differences from the initial to 12-week visit are reported with 80% CIs for the PRWE, NPRS, EQ-5D, SANE, and GRC in Table 11 (page 68). PRWE total is the primary patient reported outcome of interest.

PRWE pain scores decreased from 15.8 to 14.8 from the initial to 12-week visits for the MT group. For the NMES group, PRWE pain scores decreased from 35 to 12.3 over from the initial to 12-week visits. PRWE pain scores decreased from 21.5 to 6.3 from the initial to 12-week visits for the MT+NMES group. For the control group, PRWE pain scores decreased from 24.7 to 15.7 over from the initial to 12-week visits. PRWE function scores decreased from 21.1 to 4.4 from the initial to 12-week visits for the MT group. For the NMES group, PRWE function scores decreased from 39.8 to 8.0 over from the initial to 12-week visits. PRWE function scores decreased from 32.8 to 3 from the initial to 12-week visits for the MT+NMES group. For the control group, PRWE function scores decreased from 40 to 14.2 over from the initial to 12-week visits.

PRWE total group means at initial, 6-, 8-, and 12-week visits are visually presented in Figure 9. PRWE total scores decreased from 36.9 to 19.1 from the initial to 12-week visits for the MT group. For the NMES group, PRWE total scores decreased from 74.8 to 20.3 over from the initial to 12-week visits. PRWE total scores decreased from 54.3 to 9.3 from the initial to 12-week visits for the MT+NMES group. For the control group, PRWE total scores decreased from 64.7 to 29.8 over from the initial to 12-week visits.

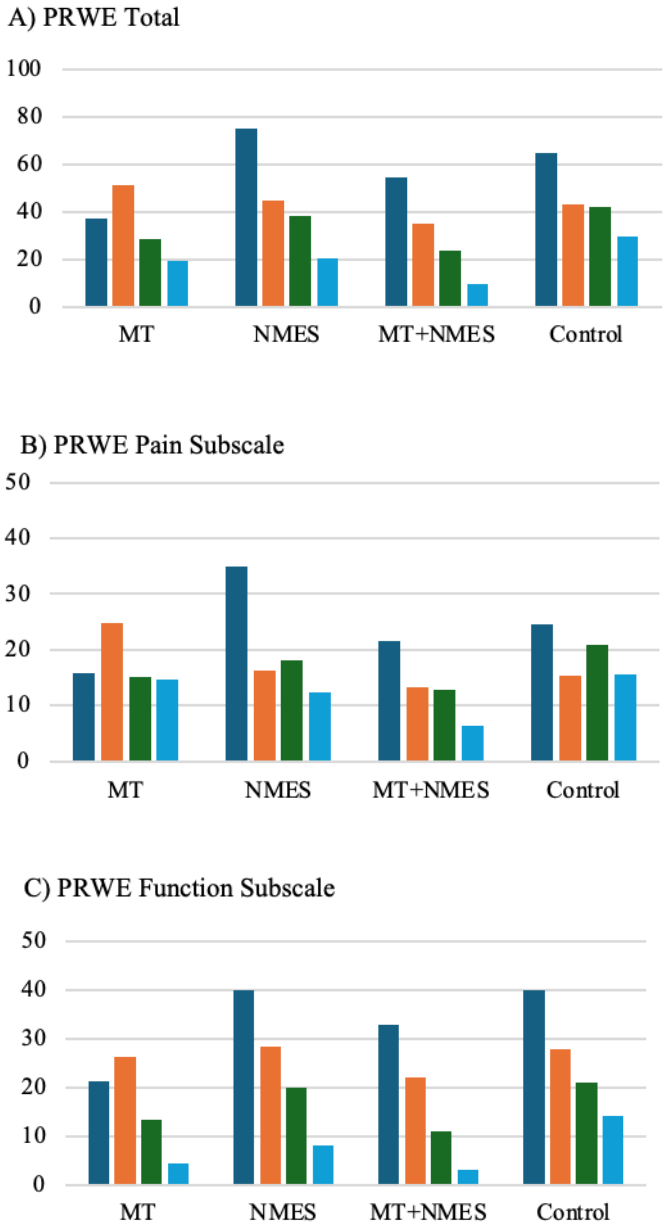

Fig. 9 PRWE A) total, B) pain, and C) function subscales scores for at the initial (navy), 6W (red), 8W (green) and 12W (blue) visits.

NPRS resting scores decreased from 1.8 to 0.5 from the initial to 12-week visits for the MT group. For the NMES group, NPRS resting scores decreased from 3.4 to 1.5 over from the initial to 12-week visits. NPRS resting scores decreased from 1.2 to 0 from the initial to 12-week visits for the MT+NMES group. For the control group, NPRS resting scores increased from 1.8 to 3 over from the initial to 12-week visits. Group means at initial, 6-, 8-, and 12-week visits can be seen charted in Figure 10. NPRS resting within group difference from initial to 12-week visits, 80% CI and standard deviations are reported in Table 11.

NPRS movement scores decreased from 3.8 to 2 from the initial to 12-week visits for the MT group. For the NMES group, NPRS movement scores decreased from 5.8 to 2 over from the initial to 12-week visits. NPRS movement scores decreased from 3.4 to 1 from the initial to 12-week visits for the MT+NMES group. For the control group, NPRS movement scores increased from 6 to 5 over from the initial to 12-week visits. Group means at initial, 6-, 8-, and 12-week visits can be seen charted in Figure 10.

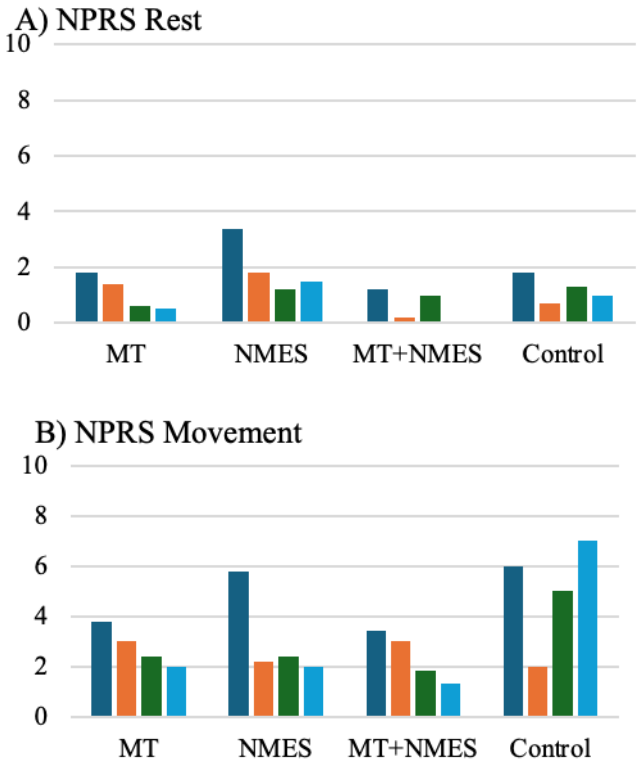

Fig. 10 NPRS pain scores A) at rest and B) during movement at the initial (navy), 6W (red), 8W (green) and 12W (blue) visits.

Table 11. Within group mean difference from initial to 12 week visits, 80% CI, and standard deviation for the patient reported outcome measures.

	MT			NMES			MT+NMES			Control		
	Mean Diff.	80% CI (Lower, Upper)	SD	Mean Diff.	80% CI (Lower, Upper)	SD	Mean Diff.	80% CI (Lower, Upper)	SD	Mean Diff.	80% CI (Lower, Upper)	SD
PRWE Total	17.8	-9.02, 44.52	16.8	54.5	30.89, 78.11	14.8	45.0	26.68, 63.32	11.5	34.8	-38.62, 108.29	29.6
PRWE Pain	1.0	-3.87, 5.87	5.9	22.8	15.82, 29.68	8.5	15.3	13.32, 17.19	2.4	9.0	-10.08, 28.08	17.5
PRWE Function	16.8	-4.34. 37.84	13.3	31.8	20.68, 42.82	6.9	29.8	10.08, 49.42	12.4	25.8	-5.23, 56.89	12.5
EQ-5D	-14.0	-22.87, -5.13	5.4	-5.3	-20.89, 10.39	19.1	-15.3	-21.98, -8.52	8.2	-12.3	-26.12, 1.45	12.7
NPRS Rest	0.3	-1.15, 1.65	0.9	2.5	.55, 4.45	2.4	1.5	-.45, 3.45	2.4	-0.7	-3.41, 2.07	2.5
NPRS Movement	0.8	-1.30, 2.30	1.3	5.0	3.51, 6.50	1.8	2.8	1.97, 3.53	1.0	1.3	-2.17, 4.83	3.2
GRC	-2.0	-3.34, -.66	1.6	-1.3	-2.03, -4.66	1.0	-2.3	-3.28, -1.22	1.3			
SANE	-38.5	-43.61, -33.39	6.3	-46.3	-52.39, -40.11	7.5	-42.3	-68.28, -16.22	31.8	-46.7	-69.33, -24.00	20.8

Note: Individuals that missed the 12-week visits are excluded from these results. Mean Diff. = within group mean difference, MT = mirror therapy, NMES = neuromuscular electrical stimulation, CI = confidence intervals, SD= standard deviation, PRWE = Patient-Rated Wrist Evaluation, EQ-5D = EuroQol-5D, NPRS = Numeric Pain Rating Scale, GRC = Global Rating of Change, SANE = Single Assessment Numeric Evaluation

4.5 Discussion

The aim of this study was to determine the feasibility of in-home NMES, MT, and MT+NMES interventions during the last three weeks of immobilization for DRF. This chapter presents interim findings for 19 out of the 72 participants to be recruited for the study. At this point the recruitment rate was on average 5 participants per month, adherence to home interventions ranges between 89 to 100%, and retention to outcome assessments was between 75 to 100%. The adherence and retention for the intervention groups meet the threshold for the green zone to proceed with the trial. The recruitment rate and retention for the control group resides in the amber zone to proceed with changes.

This feasibility RCT was designed to integrate into the existing infrastructure at HULC. Participants were recruited from urgent clinics at HULC and outcome assessments were scheduled around key recovery timelines where participants would already be on site. Some participants had appointments with the surgeon at 3-weeks, so in that case the initial visit was scheduled the same day as that appointment. At the 6-week appointment the participants had their cast removed, went to HULC hand therapy, then to the research lab for outcome assessment. The 8-week visit was scheduled based on two week follow up periods with hand therapy if their rehabilitation was being managed on site. The 12-week appointment was scheduled as a common follow up period with the surgeons.

A potential limitation to the recruitment was the lack of a full time research assistant on the project which lead to no contact for 18 potential participants. Changes in the age eligibility criteria may also facilitate recruitment. Age was one of the top reasons for ineligibility leading to 21 potential participants being ineligible, with most of these individuals being over 80 years old. This constraint was implemented due to motor imagery ability diminishing with older age and cognition (215). However, recent research into patients with post-stroke hemiplegia participating in NMES and MT using an increased frequency of treatment (five sessions vs three sessions per week) was advantageous for older adults (216). This demonstrates the five sessions a week with MT may not be as impacted as motor imagery protocols in older adults so the upper cap for age could potentially be removed.

At this interim analysis the adherence to the interventions that were 10 minute sessions, three times a day, five days a week for the last three weeks of the casting period during the immobilization period for DRF appear acceptable with adherence to the interventions ranging between 89 to 100%. This exceed the 30-50% adherence to home interventions documents for musculoskeletal populations (70–74) and >80% threshold defined for feasibility. One participant noted that they missed three days of their intervention because they left for a day trip for their child's tournament, so they did not bring their equipment, and the team did well which extended the trip two more days.

Retention to on-site visits was facilitated with outcome assessments scheduled for the same day as existing appointments at HULC when possible. Four participants, one from each group, did not attend all on-site visits. One participant disclosed their travel plans that would lead them to miss the 12-week visit prior to participating. Two participants relocated during the study leading one to miss the 12-week visit and the other to miss both the 8- and 12-week visits. The fourth participant attended the 3-week visit but none of the other visits without disclosing the reason. This participant was randomized to the control group so it is unclear whether this individual withdrew because they were not assigned to an intervention group. There was also a scheduling conflict where the researcher could not be on-site to greet the participant at their check in to their HULC appointment at the 6-week visit which may have impacted retention.

The objective outcome assessments were implemented with ease. The only challenge that arose with objective measures was that one participant in the NMES group injured their unaffected thumb (unrelated to the study) between the 6- and 8-week visits which impacted their performance and relative values. The subjective outcomes were completed by hand and there were a couple that were challenging for participants. Even with the dominant hand injured, participants did have any challenges with completed the questionnaires because in most cases they were circling items or checking boxes. There was a lot of confusion with understanding what the VMIQ-2 was asking which made it hard to participants to respond with confidence. The GRC scale was also challenging to use because they started completing the questionnaires with their cast on, which was referred to as the start of treatment, but then started rehabilitation and had a hard time distinguishing between those when providing ratings for the 6-, 8- and 12-

week visits. Given the confusion around these two measures, they may not have collected the information they were intended to.

The limited efficacy testing data demonstrates trends that may suggest a benefit from engaging with the in-home MT, NMES, and MT+NMES interventions during the last three weeks of the immobilization period. The primary outcome measures of interest are grip strength and PRWE total. The grip strength MCID falls within the 80% CI for the groups which indicates there is some change in grip strength from 8- to 12-weeks. When comparing to the existing literature reporting grip strength at one year post-DRF, a grip strength of 71% and 81% (relative to the unaffected side) has been reported after four and six week immobilization periods for DRF, respectively (102). In this study, comparable improvements are noted for the MT, NMES, and MT+NMES groups in a quarter of the time, as measured during the 12-week visit. Demonstrating 14 to 24% greater grip strength at 12 weeks post-DRF compared to the previously reported 56% of the unaffected side at 12 weeks which are compartable to the intervention groups at the 8-week visit (217).

A similar trend was seen with PRWE total scores. PRWE total scores taken 12 weeks after DRF, that were managed conservatively, report mean scores of 34 to 42 points (218,219). In this study, PRWE total scores at 12 weeks ranged between 3 and 8 for the intervention groups. The PRWE total score for the control group was 14.2 at 12-weeks.. PRWE total scores decreased more than 11.5 points (MCID) from the initial to 12-week visits for all groups. The MCID falls within the 80% CI for the groups which indicates there is some change in PRWE total from the initial to 12-week visits. That we have demonstrated that each intervention can improve grip strength and function justifies further investigation through a large RCT as to whether these interventions offer better outcomes than SoC and if any one intervention or the combination of the interventions offer superior outcomes when compared to each other.

The potential areas for improvement identified at this interim analysis was recruitement and retention to on-site visits for the control group. Whether approaches need to change will be determined upon achievement of the full feasibility sample size (N=72). Decisions can then be made about the required sample size for the full RCT using grip strength as the primary measure for the calculation. If the trends for recruitment and

retention in the control group continue as reported, a full time research assistant may be able to address these limitations for improvement and potentially remove the upper limit for age (80 years old).

4.6 Conclusion

Based on the interim results for this feasibility RCT the recruitment rate, adherence to the in-home MT, NMES, and MT+NMES interventions, retention to on site visits, and limited efficacy testing show promise for the feasibility of a large RCT. The full feasibility sample size is required to identify if the feasibility measures meet the threshold for the green zone to proceed with the trial or amber zone to proceed with changes for a full RCT.

5 Patient perspective of in-home mirror therapy and neuromuscular electrical stimulation interventions for distal radius fracture: a qualitative study

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5.1 Abstract

Introduction: Neuromuscular electrical stimulation (NMES) and mirror therapy (MT) can be applied at home and help remediate resulting impairments from extremity disuse. Application of these interventions during immobilization for distal radius fractures (DRF) may be a preventative strategy to mitigate the resulting impairments from disuse during immobilization. The aim of this qualitative study was to capture the patient perspective of in-home NMES, MT and MT+NMES interventions during immobilization for DRF to determine their practicality and acceptability.

Methods: Participants were recruited as part of a feasibility randomized controlled trial (RCT) taking place at the Roth| McFarlane Hand and Upper Limb Centre (HULC) Participants were randomly assigned to the MT, NMES, MT+NMES, or control group. Interventions were 10 minute sessions, three times a day, five days a week for the last three weeks of immobilization. The participants engaged in a semi-structured interview the day their cast was removed. Practicality and acceptability were determined qualitatively based on participant remarks. An interpretative description approach was used.

Results: Fifteen participants completed interventions and the semi-structured interview. Six themes identified from the transcripts included: accommodations for an easy commitment, time is limited, roadblocks to engagement, ‘it’s a win win’ situation, setting expectations and building confidence, and shock and awe..

Discussion: Facilitators for these interventions were participants that were advocates for research, had flexible schedules, and all the intervention equipment was provided. The main barriers discussed were transportation for on-site visits and the time commitment. Participants reported the time commitment to the interventions during the immobilization period appeared to reduce the time commitment to rehabilitation after the cast was removed, improve outcomes, and timelines to return to activities. Based on participant feedback the in-home interventions were practical and acceptable.

Conclusion: Participants recommended that in-home MT, NMES, and MT+NMES interventions applied during immobilization for DRF become more widely available and that all DRF patients do it if they can.

Keywords: neuromuscular electrical stimulation, mirror therapy, distal radius fracture, interpretative description, semi-structured interview

5.2 Introduction

When an upper extremity is immobilized there are resulting impairments that include reduced muscle tolerance, muscle atrophy, and reduced function due to the disuse of the extremity (180). Distal radius fractures (DRFs) are one of the most common fractures in adults and are treated with surgical intervention or with a closed reduction, followed by applying a cast for four to six weeks (89,179,220). This period of disuse during immobilization of the wrist results in muscular atrophy, and reduced strength, range of motion, and function (113,115). Once the cast is removed, patients attend physiotherapy to improve strength, range of motion (ROM), and function. Patients experience variable recovery where some have persistent impairments over a year after fracture (178). Therefore, it would be advantageous to find an intervention that could be used during immobilization to mitigate the resulting impairments by starting rehabilitation earlier.

Neuromuscular electrical stimulation (NMES) and mirror therapy (MT) are interventions that have been used with populations that experience impairments from periods of disuse of an extremity. NMES is a non-invasive modality in which electrodes are placed on the skin over target muscles and current is passed through the electrodes to the muscles. Mirror therapy (MT) is a form of mental practice using a mirror set up in the sagittal plane facing the unaffected extremity with the affected extremity resting out of sight. The reflection of the unaffected extremity is watched as movements are performed providing the visual experience that the affected arm is unimpaired and performing the movement. Application of MT and NMES interventions during disuse have been shown to improve motor function, strength and range of motion (ROM), and reduce pain (13,34,37,45,46,169). MT and NMES may be feasible options to apply during the immobilization period for DRFs because the fracture remains protected for healing to occur since there is no active movement of the affected wrist and they can be done in-home.

Furthermore, materials for MT and NMES interventions are readily accessible for purchase and relatively inexpensive interventions, allowing them to be done at home. NMES devices can be purchased online for under $100 CAD and MT

equipment (16” by 20” mirror and table easel) can be purchased online for ~$80 CAD. People could use mirrors they already have at home if they can set them up appropriately for the intervention. The benefit of MT and NMES is that the patient can be taught how to appropriately set up the interventions and how to safely engage in a program at home. By using in home interventions, people do not require significant financial resources, allowing them to save on extended health benefits, which they will need for physiotherapy after the cast is removed.

A common challenge seen with home exercise programs is adherence. Adherence is considered the extent of engagement with the recommendations for an intervention (221). Individuals are classified as adherent to programs if they achieve 70 to 75% engagement in the programs. Adherence rates for home exercise programs for musculoskeletal cohorts range between 30 and 50% (70–74). Low adherence rates can negatively impact the feasibility and effectiveness of the program, so finding a way to improve adherence can improve outcomes and minimize use of resources. Home exercise programs can improve access to rehabilitation, particularly when individuals are unadvised to drive while wearing a cast. MT and NMES are cost-effective options that can be used at home during immobilization of DRF when transportation can be a challenge. In-home MT, NMES, and MT+NMES intervetions applied during immobilization of DRF are being assessed with a feasibility randomized controlled trial (ongoing recruitment and data collection). The aim of this qualitative study was to capture the patient perspective of in-home MT, NMES, and MT+NMES interventions applied during immobilization of DRF with a semi-structured interview at 6-weeks post-DRF.

5.3 Methods

This qualitative study was conducted as part of a feasibility randomized controlled trial (RCT) to capture the patient perspective on their experience with the in-home MT, NMES, MT+NMES interventions. The trial was approved by the Human Research Ethics Board at the University of Western and was registered with ClinicalTrials.gov (NCT05925673). The research was conducted collaboratively with Lawson Health Research and the University of Western Ontario.

5.3.1 Recruitment

The randomised controlled trial took place at the Roth| McFarlane Hand and Upper Limb Centre (HULC) in London, Ontario, Canada. The clinic serves a large catchment in London and surrounding communities with over 40,000 patients visiting HULC each year. Patients with acute injuries of the upper extremity are referred from urgent care clinics to HULC for surgical consults during an urgent clinic. Patients who sustained a DRF in the last three weeks were approached at the urgent clinic. Patients not interested in participating were thanked for their time and no further questions were asked.

Participants were eligible if they were 18 to 80 years of age, able to understand English instructions, were being managed non-operatively for a DRF sustained in the last three weeks, and able to provide informed consent. Participants were ineligible in the presence of cognitive disorders that could preclude the participant from following instructions for the home interventions, had visual impairments that would limit their ability to engage in the interventions, had superficial metal implants in the injured arm, active cancer, severe peripheral vascular disease and/or thrombophlebitis in the injured arm. Cognition disorders were identified as formal diagnoses and informal assessment in the individuals' ability to understand the intervention during recruitment.

5.3.2 Intervention and Outcome Assessment

The schedule for the three intervention groups, was 10 minute sessions, three times a day, five days a week for the last three weeks of the casting period. Individuals were randomized to either MT, NMES, or MT+NMES in addition to standard of care (SoC). The control group engaged in SoC alone. At the initial session (3 weeks post-DRF) participants were supplied with the materials for the intervention, an instructional booklet, and session tracker. The MT, NMES, and MT+NMES interventions and the outcomes assessed during on site visits at 3-, 6-, 8-, and 12-weeks post-DRF are outlined in Chapter 4. Site visits ranged from 45 to 90 minutes for a maximum time commitment of 13 hours for the study including 7.5 hours of in-home interventions totaled over three weeks and 3.5 to 5.5 hours for follow up visits at HULC. Follow up visits were scheduled the same days as existing

appointments to see the HULC surgical and hand therapy teams when possible. No compensation was offered to participants, other than parking reimbursement for on-site visits.

5.3.3 Semi-Structured Interview

At the 6-week follow up visit, participants in the intervention groups engaged in a semi-structured interview to inquire about their positive and negative experiences with the intervention and on-site visits. Interviews were recorded and transcribed using Microsoft Teams. Audio recordings were stored on the hospital network drive after transcription was complete. Personal identifiers were removed from the transcripts for analysis. The full interview guide is attached as Appendix E.

5.3.4 Data Analysis

An interpretative description approach was used for the interviews (197). Analysis of the interview transcripts were done manually and concurrently with collection. The first step of analysis for the transcripts was sentence by sentence with open coding. The codes compared between transcripts to identify similarities and potential themes. Subthemes were developed though grouping recurring themes. Axial coding was used to link subthemes to other related codes. Continual comparison and discussion of identified subthemes and codes during analysis were organized into subthemes until no further subthemes could be established.

Subthemes were assessed to ensure a relationship to the study interventions and procedures. The last step of analysis was selective coding, where themes were compiled to convey the experiences with using early interventions for DRF during immobilization (222). The researchers met to discuss any disagreement with content analysis and/or selection of quotes. The researchers involved in data analysis engage in physical therapy research and clinical education/practice. The themes identified were considered for to determine the practicality and acceptability of the interventions.

5.4 Results

5.4.1 Participants

Ninteen participants were deemed eligible and consented to participate in a feasibility RCT. Participants were randomized to MT, NMES, MT+NMES, or control groups. The 15 participants from the RCT that were randomized to the three intervention groups participated in this study. Group demographics are reported in Table 13.

Table 11. Intervention group demographics

	MT	**NMES**	**MT+NMES**
Age (Mean ± SD)	64 ± 14.5	60 ± 8.9	47 ± 19.6
Sex (M / F)	1 / 4	1 / 4	1 / 4
Injured Side (L / R): % Dominant	3 / 2 40%	2 / 3 60%	3 / 2 40%
Sessions Completed:	40 ± 7.6	45 ± 0	43 ± 4.0
Days Since Fracture: Initial Visit 6 Week Visit 8 Week Visit 12 Week Visit	 21 ± 1.2 41 ± 4.5 61 ± 6.8 87 ± 2.6	 20 ± 1.3 43 ± 3.2 60 ± 3.1 85 ± 5.0	 19 ± 4.3 43 ± 6.6 57 ± 2.2 81 ± 6.1
Employment Status (n): Going to Work Working from Home Temporary Leave Homemaker Retired	 - - 1 1 3	 1 1 - - 3	 - 1 1 1 2

MT = mirror therapy, NMES = neuromuscular electrical stimulation, SD = standard deviation, M = male, F = female, L = left, R = right

5.4.2 Timeline

Participants engaged in home MT, NMES, or MT+NMES interventions for the last three weeks of their casting period. Following removal of their cast, participants completed the semi-structured interviews about their experience with interventions. The interviews happened in person on the same day as their cast removal after the patients consulted with the surgical team and hand therapy team at HULC.

5.4.3 Patient Perspective

All 15 participants randomized to intervention groups engaged in a semi-structured interview after completing the interventions. Six themes identified from the transcripts include accommodations for an easy commitment, time is limited, and roadblocks to engagement, it's a win win situation, setting expectations and building confidence, and shock and awe.

5.4.3.1 Theme One: Accommodations for an easy commitment

Participants were provided packages with an instructional booklet and all the equipment for the intervention so "having all the materials with me, so even having the mirror provided made it very easy. Having the instructions written down in the booklet was really easy, so that, especially having the photos in there, it was just nice to always have my questions answered in a way that was really accessible for me." Participants also found "the setup was really easy to do and it was really easy to place it in my home where it wasn't disruptive. I could I could disassemble it if I didn't want it to be there. So it was quite quite user friendly and easy to use." The ability to engage in the program at home was a facilitator for adherence to the program because "You're at home. Didn't have to travel" and "if you had to come back every day somewhere to do it, no" it would not be feasible to participate.

Participants expressed the 10-minute sessions, three times a day were feasible with their schedule because "I could do it at my own time, so it wasn't like one specific set time I had to do it. So you know, it was pretty easy to fit it in." They also found "the fact it was only five days a week was helpful because there was two days, both weeks when I couldn't have done it. I was away." To be feasible with their schedule some participants "changed it a bit, so to my schedule. Yea." Another participant "used it like after work and then before I go to bed." so they did two 15-minute sessions a day. There were some adjustments to how the exercises were performed as well because the images for the exercises are so structured and a participant found it challenging to imagine the movement like that. Once they loosened their hand position to something that was more natural for how they move their hand, it was easier to feel the movement.

In cases where the timing was appropriate, on-site visits were scheduled for the same day as existing appointments for the patients at the clinic. Participants liked this as noted by stating “It's convenient because it aligns with my already scheduled doctor's appointments and I do need to get a ride because of my injury, so just getting a ride is the inconvenient part, but I already need to get the ride anyways.” The flexibility of the researchers waiting to see participants after they have completed their preceding appointments was also noted as a positive for the on-site visits. “Umm. Maybe being available because you don't know when I'm going to be done, so being available whenever I'm available. So that's that. That's been great.”

5.4.3.2 Theme Two: Time is limited

Overall patients were happy with their involvement in the study and were really trying to reflect on their experience to share constructive feedback that could be used to improve the program. One participant suggested considering if three sessions a day is needed “Is 2 enough? The third time was always the hardest, three a day was the hardest. I guess it depends on what the lifestyle is too, right?” This connects to the time commitment being the largest point of discussion for potential drawbacks to the study. Time commitment to the intervention was the most common drawback for participating that was discussed. “Well, it's a time commitment…. To me it wasn't huge, but for some people it might be.” Some participants recognized that the time commitment was based on the expectations for the time they will need to commit to their rehabilitation program once their cast is off. For others this was not acknowledged until after the first hand therapy visit where they noted “I struggled getting the time sometimes. Honestly, now I realize, like I do all these exercises with my cast off. How in the world will I get all this done, if I struggled to get that done.” In discussing the time commitment, some participants highlighted that it should not really be a drawback. “I don’t think there are any drawbacks. The only thing would be if someone didn't have the time, but it it's not really an issue in my view because it's 10 minutes, three times a day. So it's quite achievable even if you were to be still working or anything like that.”

5.4.3.3 Theme Three: Roadblocks to engagement

Some unexpected challenges came up during the interview process related to equipment, personal factors, and environment that impacted engagement. For

participants using the NMES machines, there were some challenges with the electrodes sticking. “I didn't know when I should give up on the first set of electrode pads. I switched to the second and they got less sticky kind of soon.” Other participants noted they just washed the electrodes with water and that improved their adhesion to the skin so they could keep using the first set for longer. For participants for whom their affected side was their dominant side, they expressed challenges with using the tracker suggesting “Um maybe sending like a Google doc to the person and then they can just fill out the data electronically or like even dictate it because the first couple days I couldn't even write like barely.”

5.4.3.4 Theme Four: It’s a win-win situation

When participants were asked about why they agreed to participate, and the benefits of participating in the study, many highlighted the appeal of participating in the study is “contributing to research and hopefully I'll have better outcomes.” This sentiment was shared by another participant stating their reason for participating was to “support research and then also an interest in the goals of the program, so increasing mobility and stuff like.” and “I thought, you know, there's no harm. I think you know if there's a chance that potentially recovering sooner is a possibility, I'm willing to to lend a little bit of time to that study.”

Most of the participants expressed an appreciation for research whether they were involved in research during their career, work in the medical field, and/or value the importance of research for advancing healthcare.

“My background is a nurse and just the importance of doing these studies was a big factor for sure and just trying to improve outcomes down the road.” Another participant expressed this sentiment in sharing “I'm a believer in research because I did a thesis with my masters, so I know how important research is.” Many participants viewed their involvement as an opportunity to pay it forward. “This can eventually then help others to to learn that doing this is going to help you heal faster through your study or your colleagues or whatever. I think it's great. So why not? It was a win, win situation.” and “If it benefits me, great. If it benefits other people getting better, perfect, that's awesome.” It was noted that research participation is important “to help further

medicine along in the advancement of making everybody better." The personal gain from participating in the study was presented as more of a second thought to participating in research for a handful of participants. "The benefit would be getting to contribute to research and as well as being given the opportunity to try something that is aimed at increasing mobility and helping afterwards."

Participants also started to enjoy the interventions. "Uh, well, once I got used to it, then it was, you know, kind of like, OK, I look forward to that kind of." One participant noted the stimulation "was actually really relaxing if it felt very good" so much so that they purchased themselves a machine. This perception was not limited to the physical sensation of the stimulation. Another participant noted "I found them comfortable. Like I found the sensations. Especially uh, like while I was doing it with the mirror, I found the arm sensations very comforting and felt very nice." Between the pleasant sensation of the interventions, the potential benefits for their recovery, and contributions to research, participants were pleased with their involvement in the interventions.

5.4.3.5 Theme Five: Setting expectations and building confidence

Participants expressed their expectations for when their cast would be removed based on feeling the changes expressed as "within that first and 2nd appointment I was like oh my gosh, I already can't do this…. it's amazing how fast you lose things." As well as managing expectations from others after the cast is removed "everybody was telling me that, you know, you're not gonna be able to do anything." The idea that the early intervention could potentially improve their outcomes after the cast is removed made sense to them as it is "kind of like the use it or lose it sort of idea" and "the logic behind it makes sense. … Like it's like ding ding. Yeah, that can't not work." Having a confidence in the logic behind the proposed improvements helped build confidence in the interventions and excitement around their recovery as noted with "the electrodes…get the nerves working. You get the stimulation so at this point now where I'm starting to move it more, it's gonna come back quicker."

Participants reported a true belief that the interventions have "been helpful I feel…Even without knowing" and "helped me so much and I felt that much better because of the

muscles, the way they were contracting" (P9). Even participants that did MT noted how the exercises were helpful and with imagining the movements "I could feel it" and shared "with the sensation that I got in the opposite arm I was intrigued." Having a positive experience with the interventions made participants excited about getting back to their activities sooner with participants stating "I'm gonna be able to garden quicker than I would have."

5.4.3.6 Theme Six: Shock and awe

All the participants were grateful for the opportunity to engage in the early interventions. They attributed their participation in the intervention to their successes with outcomes, recovery time, and returning to activities. Facilitated recovery timelines were noted with some participants having their casts removed earlier than what was projected initially and some even being discharged from the surgeon and hand therapy teams just six weeks after their fracture. Participants perceptions of their facilitated progress was reinforced with feedback from the medial team as noted with "other people are surprised at how well I'm able to move my arm and that right away. And even the doctor was. When the cast was removed, so I told him about the study because he goes oh, wow, you're actually moving that fairly well. And I said well, I'm involved in this study. So yeah, I was. I was quite surprised." In this case the participant had their cast removed two weeks earlier than expected despite a DRF and carpal fracture.

Another participant shared "I think I've already shown some of the outcomes were favorable according to the doctor and physiotherapy, when they looked at my range of motion, they all were kind of surprised." Before getting the cast put on, this participant was told they would have to wait at least four weeks after the cast is removed to return to playing hockey. With approval from the surgeon, he was playing hockey a week after his cast was removed. Participants were impressed with the status of their wrists when the cast were removed "I feel that coming out of my cast, I was really strong. I like they were actually surprised at how how it was able to move my hand right away too… It was pretty amazing to me."

For those engaging in MT, "It wasn't a challenge, really to do the exercises. That was it was imagining, trying to imagine" that participants found difficult. A personal factor that proved to be a challenge for one participant was their unaffected wrist was

compromised from a previous surgery “so it um because I've been using it so much and the exercises on top of it. You know, I was grateful for the rest days on the weekends because I did need recovery time.” This ultimately did not prevent participation in the program with 100% adherence for this participant. Only three participants noted adherence to the interventions of less than 100%. One of those participants noted “There's some days I didn't do it. I wasn't even home. I actually went to OFSAA with my kid for hockey and complete. I thought I was just going for the day ended up staying for night and the next night I stayed” where the equipment was left at home because the overnight stay was unplanned. Another participant that engaged shared they “actually got kind of motion sick” when performing exercises in front of the mirror. Once they found the right position for the mirror, they were able to perform the intervention without the motion sickness, but this limited their engagement with the intervention.

Some participants did not have any specific challenges or areas of improvement to note other than increasing the accessibility of the program to improve engagement. “You know, honestly, I just think more people should be kind of like aware of of its availability. Because when I talk to people outside of the hospital and told them what I was doing, they were like, that's really excellent. That's so that's cool that you could participate in this…So yeah, I think just more awareness, I suppose.” This sentiment was shared with multiple participants stating “I think everybody that can do it should do it. It's uh just for the research part end of it. And if they can heal faster, that's better” and “I think it's pretty good. Like, I think everybody should do it. Like, you know, it will help everyone.”

5.5 Discussion

The aim of this qualitative study was to capture the patient perspective for in-home MT and NMES interventions during the immobilization period for DRFs. Six themes were identified including accommodations for an easy commitment, time is limited, and roadblocks to engagement, it’s a win win situation, setting expectations and building confidence, and shock and awe. The first three themes speak to the the practicality of the interventions, while the last three themes speak to the acceptability of the interventions.

Although the time commitment was feasible for the participants in the study, it was the biggest point of discussion around challenges or drawbacks to participating. Interestingly, in some cases the time commitment to these interventions during casting reduced the time requirement for rehabilitation after the cast was removed. A trade-off for an increased time commitment during the casting period would be more favourable given the limited participation in usual activities and work compared to an individuals' standard schedule without a cast on and increased time demands once the cast was removed.

The flexibility in the schedules of the participants involved in the study during the casting period speaks to the practicality of implementing the in-home MT, NMES, MT+NMES interventions during the immobilization period for DRF. Of the 19 participants, only 2 were leaving the house to attend work during the intervention period. The remaining 17 participants were on leave, working from home, homemakers or retired. Many individuals that sustain DRFs are on leave or modified duties at work while they are recovering from the DRF, hence, they likely will have similar flexibility with their schedules. Roughly 20% of individuals that have sustained a DRF report no loss of time at work (115). If they are working outside of their homes, the feasibility of the interventions and attending on-site visits may not be as high for this cohort.

Additional facilitators for the practicality of the intervention include providing the participants with the equipment and instruction packages for the duration of the intervention. Conducting the study at the HULC in London, Ontario, Canada was also a facilitator for the study with improved access to individuals with DRFs. The urgent clinics at HULC were an ideal setting to recruit patients in the first three weeks of them sustaining a DRF. HULC is a highly regarded institution and has high engagement in research. This was also reflected in the high regard for research by the patient population. Most of the participants in this study valued research, so other settings and individuals with less of an emphasis on the research may not have as much success with recruitment. The draw of HULC for surrounding areas in Ontario did prove to be a barrier for recruitment.

Participants were accepting of the interventions because the theory behind the interventions made sense to them. The sensation the participants experienced with the

interventions made them feel like the interventions were productive and helpful during the immobilization period. Their ability to move their wrist and participate in activities right after the cast was removed was a surprise to them and their healthcare them. One participant was even approved to play hockey one week after his cast was removed, even though he was told it would be at least four weeks after the cast was removed at the time of his initial visit. Participants attributed their involvement in the interventions to improved outcomes, faster recovery timelines, and return to activities. Multiple participants expressed everyone with a DRF should do the in-home interventions during the immobilization period.

5.6 Conclusion

Participants that completed in-home MT, NMES, and MT+NMES interventions during the last week of their casting period for DRF expressed the interventions were practical and acceptabkle. Participants were recruited from HULC, advocates for research, had flexible schedules from home, and provided all the intervention equipment which were facilitators for the program. The main barrier disclosed was transportation for on-site visits and the time commitment, but patients noted the time commitment to the interventions during the immobilization period appeared to reduce the time commitment to rehabilitation after the cast was removed, improve outcomes, and timelines to return to activities. Participants recommend the program become more widely available and that all DRF patients should do it if they can.

6 Implications of mirror therapy and neuromuscular electrical stimulation on immobilization induced electromyographic changes after distal radius fracture.

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6.1 Abstract

Introduction: Distal radius fractures (DRFs) require a prolonged period of immobilization for the bone to recover. The disuse during immobilization results in muscle atrophy and decreased strength. Electromyography is a technique that can be used to detect muscle activity during muscle contractions. Mean power frequency (MPF) and root mean square (RMS) are two measure that reflect motor unit recruitment strategies and reflect muscle fatigue during sustained contractions. The aim of this study was to investigate whether MPF and RMS differ between the individuals with DRF that participated in mirror therapy (MT), neuromuscular electrical stimulation (NMES), MT+NMES interventions during immobilization for DRF on MPF compared to standard care.

Methods: The participants in this study were a cohort of nineteen individuals that sustained DRF in 8 to 12 weeks prior to this study and were managed conservatively. Fifteen of the individuals participated in MT, NMES, or MT+NMES interventions during the last three weeks of their casting period.

Surface electrodes were placed over extensor carpi ulnaris (ECU), extensor carpi radialis (ECR), flexor capri ulnaris (FCU), and flexor carpi radialis (FCR) on the left and right side. Electrode placement was determined based on palpation of the muscles during active combined movements. Participants completed three 5-second MVCs for ulnar deviation, wrist flexion, radial deviation, and wrist extension using a table top for resistance during the isometric contraction.
Results: No differences differences in MPF or RMS were detected between the three MVCs.

Discussion: The procedure for the MVCs and timing of analysis may limit the ability to detect fatigue given the short five second MVCs with rest between. A longer sustained contraction may be more appropriate to assess fatigue from the start to end of the contraction.

Conclusion: This was the first study to compare EMG activity after engaging in interventions during the casting period for DRF. Changes in MPF and RMS were

not detectable with three to five individuals in each group and potentially due to the comparison between three 5- second MVCs. Future investigations may be better able to detect fatigue and MU recruitment patterns with comparison of the start, middle and end of a longer sustained contraction and including force measurement.

Keywords: distal radius fracture, early interventions, electromyography, root mean square, mean power frequency, maximal voluntary contraction

6.2 Introduction

Prolonged immobilization is often necessary for treating upper and lower extremity musculoskeletal conditions. Approximately six weeks of immobilization is required to allow for callus formation, soft tissue and/or bone healing (96,97). During immobilization there are adaptations in the central nervous system and local muscles resulting in muscle atrophy, reduced strength, mobility and function (113–117). Months of physiotherapy are then required to address the resulting impairments. It would be beneficial to find strategies that can target the affected pathways during the immobilization period to mitigate the resulting impairments. Two interventions that could potentially mediate the resulting impairments from immobilization, and can be applied during immobilization, are mirror therapy (MT) and neuromuscular electrical stimulation (NMES). MT and NMES have central and local sites of adaptation, respectively.

Studies using transcranial magnetic stimulation (TMS) report that observing the reflection during MT facilitates the primary motor cortex excitability on the ipsilateral side and demonstrates increased corticospinal pathway excitability (6–9). During this immobilization period there are decreases in corticospinal excitability (181–183). The decreases in corticospinal excitability could be due to decreases in motor cortex and/or spinal motoneurons. When excitability is decreased, greater synaptic input is required for the motor cortex and/or spinal motoneurons to maintain muscle activation with sufficient intensity for sustained contractions (223,224). During maximal muscle contractions, an increase in neural drive is not available to compensate for the decreased corticospinal excitability so motor unit (MU) recruitment and muscle activation are reduced as a result of central fatigue (223–227).

NMES can be used as a passive modality over an inactive muscle to evoke a contraction in muscles where active movement is unavailable (23). Disuse of the muscle leads to reduced protein synthesis and muscle atrophy. NMES has been reported to increase protein synthesis and decrease muscle atrophy (24–27). In atrophic conditions, there is conflicting evidence on whether type I or type II MUs

are more vulnerable (145,146). NMES simultaneously recruits all local MUs, unlike voluntary contractions where type I MUs are recruited before type II MUs (28), so type II MUs are recruited earlier with NMES than with active contractions (25,29,30).

MT and NMES applications during immobilization may be able to maintain pathways for MU recruitment at a central and local level. Surface electromyography (EMG) is a method for recording muscle activity where MU recruitment can be assessed. Mean power frequency (MPF) is a form of EMG analysis that could provide insight into MU recruitment strategies (149–151). MPF is greater with increased amounts of force, potentially due to greater recruitment of Type II MUs for a quick increase in force production (161,162). During sustained contractions, MPF decreases due to the increased fatigability of the type II MUs (155–158). This MPF pattern is reflective of fatigue (153,228). Root mean square (RMS) of an EMG signal can provide information about the intensity of a muscle contraction as it reflects the sum of the action potentials of the MUs during the contraction. RMS has an inverse relationship to MPF where it increases as fatigue accumulates (152–154). The increase in RMS reflects an increase in MU recruitment to maintain the force of the contraction as MUs fatigue (159,163). It has been suggested that greater increases in RMS, with concurrent decreases in MPF, reflect greater recruitment of type II MUs as a result of fatigue (160,164,165).

After just one week of wrist immobilization in healthy volunteers there was a decreased maximal contraction, but no change reported in muscle contractile properties (229). This suggests the initial loss in strength during immobilization is due to central nervous system adaptation, rather than local adaptations in the muscles. With longer periods of immobilization, muscle atrophy is reported, with a greater impact on females (24). With four to six weeks of immobilization (van Delft et al., 2023) and a larger incidence of DRF in females, DRF would make a good model to investigate the impact of MT and NMES on MPF and RMS for maximal muscle contractions in the wrist. The aim of this study was to compare MPF and RMS during maximal contractions of wrist flexion, radial deviation, ulnar deviation,

and wrist extension at 8-weeks post-DRF after completing MT, NMES, MT+NMES and standard care for DRF.

6.3 Methods

Participants were recruited at the Roth| McFarlane Hand and Upper Limb Centre (HULC) in London, Ontario. Participants attended HULC for outcome assessments but completed the interventions in their homes. These data were collected as part of a a feasibility randomised controlled trial (RCT) with a four group design comparing in-home (a) MT + standard of care (SoC), (b) NMES + SoC, (c) MT+NMES + SoC, and (d) SoC (control) for DRF. Intervention details and SoC are documented in Chapter 4. Participants were allocated to the groups through sealed, opaque envelopes that were sequentially assigned upon consent to participate. To be included in the study participants were 18 to 80 years of age, able to understand English instructions, sustained a DRF in the last three weeks and were being managed non-operatively, and able to provide informed consent. Participants were ineligible for the study in the presence of cognitive disorders and/or visual impairments that would limit their ability to engage in the interventions, superficial metal implants in the injured arm, active cancer, severe peripheral vascular disease and/or thrombophlebitis in the injured arm.

6.3.1 Interventions

All three interventions started three weeks after the DRF was sustained. The sessions were 10 minutes, three times a day and performed five days a week for the last three weeks of immobilization. Participants completed a total of 45 sessions during the three-week interventions. Participants were provided an instructional booklet, intervention materials and a session tracker at the initial visit. A 16” x 20” mirror and tabletop easel was provided for MT interventions. Participants were instructed to set up the mirror on the easel along the midline of their body so they could see a reflection of their unaffected arm in the mirror when they held it up. The affected arm was out of sight and relaxed during the intervention.

Participants performed two sets of five hand/wrist exercises with the unaffected hand in front of a mirror. The first four exercises included making a fist and

extending the fingers, wrist flexion and extension, ulnar and radial deviation of the wrist, as well as pronation and supination for 10 repetitions each. The fifth exercise was six wrist circles in one direction and six in the reverse direction for a total of 12 wrist circles. Participants were instructed to watch the reflection and try to imagine the unaffected hand also performing the movement while it remained resting. Each repetition was paced to take six seconds to complete.

NMES was applied using an Intensity Twin Stim III kit. Two 1.25" round electrodes over the proximal region of their wrist flexors and another two over the proximal wrist extensors along the border of the cast. The device was set to EMS, alternating, pulse duration of 300 μs, pulse frequency of 50 Hz, ramp up one sec., contract two sec., and ramp down one sec for the intervention. The stimulation alternated between the wrist flexors and wrist extensors with one sec. ramp up, 2 sec. contractions and one sec. ramp down for each. Participants were encouraged to use the highest intensity tolerable without visible movement at the wrist. Electrode placement was determined individually for each participant where they could feel the stimulation extending distally along the wrist flexor and extensor muscle groups under the cast.

For the combined MT+NMES intervention, performed the exercises in front of the mirror while NMES was applied to the resting affected extremity out of sight. Each repetition of the exercises was performed over six seconds to coordinate the exercises with the NMES timing. Participants were instructed to pair the stimulation for the wrist flexors with the phase of the exercise that increases wrist flexor activation and the stimulation for the wrist extensors to be matched with the phase of the exercise that increases wrist extensor activation.

6.3.2 Electromyography

Participants attended two sessions at HULC between eight to 10 weeks and at 12 weeks post- DRF for EMG recordings. The Delsys Trigno Wireless Biofeedback System was used to assess EMG for the extensor carpi ulnaris (ECU), extensor carpi radialis (ECR), flexor capri ulnaris (FCU), and flexor carpi radialis (FCR) (Figure 11). Palpation with active movement from the participant was used to locate the muscle and place the electrodes.

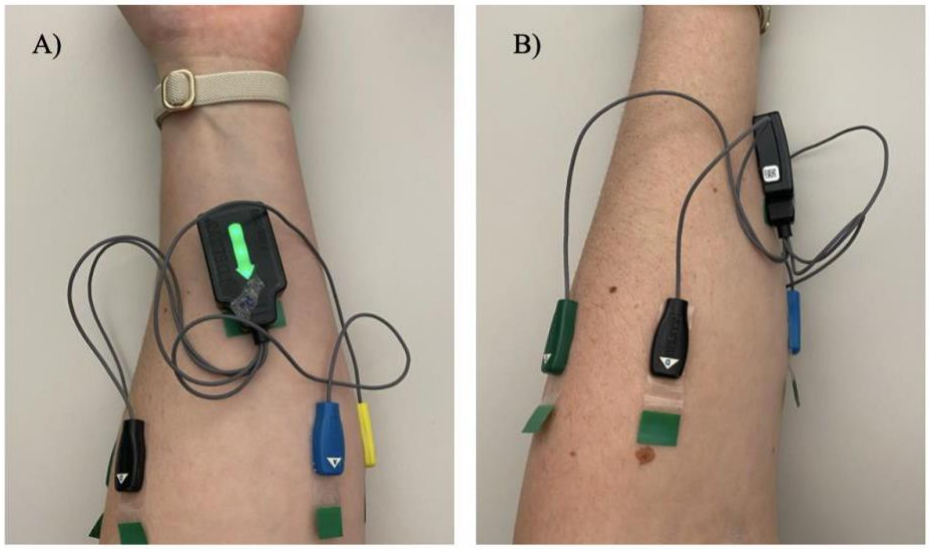

Fig. 11 EMG electrode placement for extensor carpi ulnaris (green), extensor carpi radialis (black), flexor capri ulnaris (blue), and flexor carpi radialis (yellow).

Participants were seated with their elbows by their side and arm extended to place their hand on the table for wrist flexion and ulnar deviation where they pressed down into the table for the maximal voluntary contractions (MVCs). For wrist flexion, participants were told to make a fist with their hand and with their palm facing down place their hand on the table with their wrist off the edge. For ulnar deviation, participants were told to extend their fingers and keep them together while they set their 5th digit on the table and wrist off the edge. For wrist extension and radial deviation participants set their hand under the table to push up into the table for the MVCs. For wrist extension, participants were instructed to make a fist and push the dorsal side of their hand in contact with the table. For radial deviation, participants were told to make a fist with their thumb tucked in and the side of their first finger in contact with the table. Set up for MVC contractions can be seen in Figure 12. Participants performed five second MVCs for wrist flexion, ulnar deviation, radial deviation, and wrist extension. MVCs were repeated three times for each of the four movements and performed with both the left and right hands.

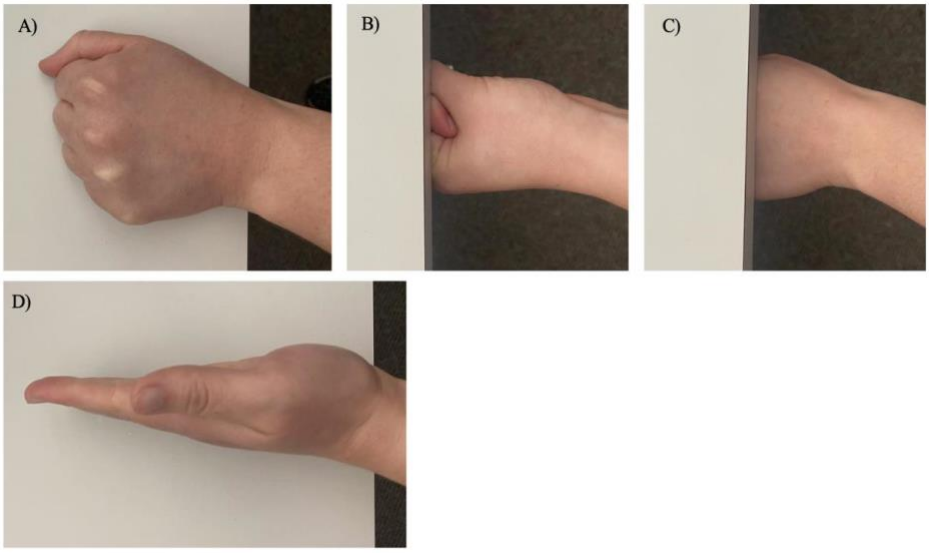

Fig. 12 An aerial view of MVC contraction positioning for A) wrist flexion, B) radial deviation, C) wrist extension, and D) ulnar deviation.

6.3.3 Analysis

Data were extracted from Delsys EMGworks software. MPF and RMS values were individually calculated for all four EMG channels for all four wrist movements on the affected and unaffected sides. The output was exported into Microsoft Excel to analyse the MPF and RMS of the EMG recordings.

6.4 Results

For each muscle contraction there were two muscles of focus. Figures 13 to 16 present data for the affected side. Mean values for FCU and FCR muscles presented for wrist flexion in Figure 13. Mean values for ECU and ECR muscles are presented for wrist extension in Figure 14. Mean values for ECU and ECR muscles are presented for ulnar deviation in Figure 15. Mean values for ECR and FCR muscles are presented for radial deviation in Figure 16.

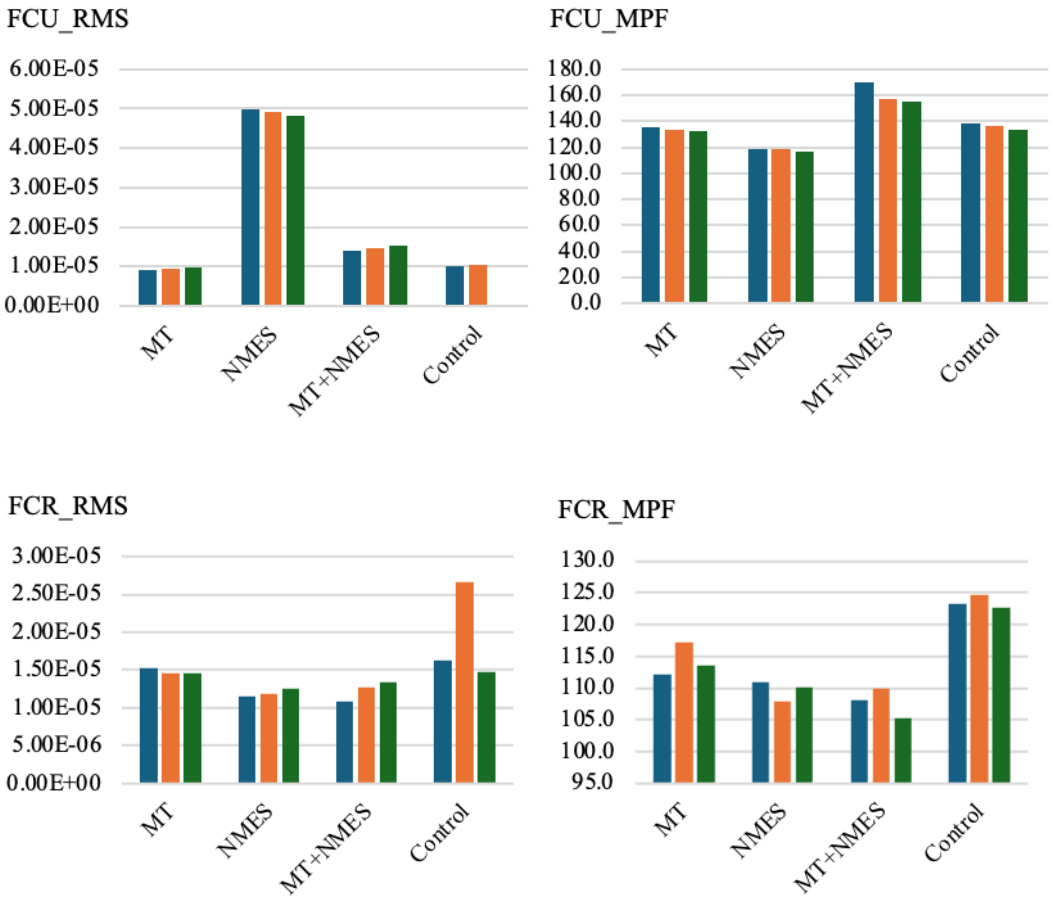

Fig. 13 RMS and MPF for FCU and FCR during wrist flexion contractions on the affected side for the first (blue), second (orange), and third (green) contractions.

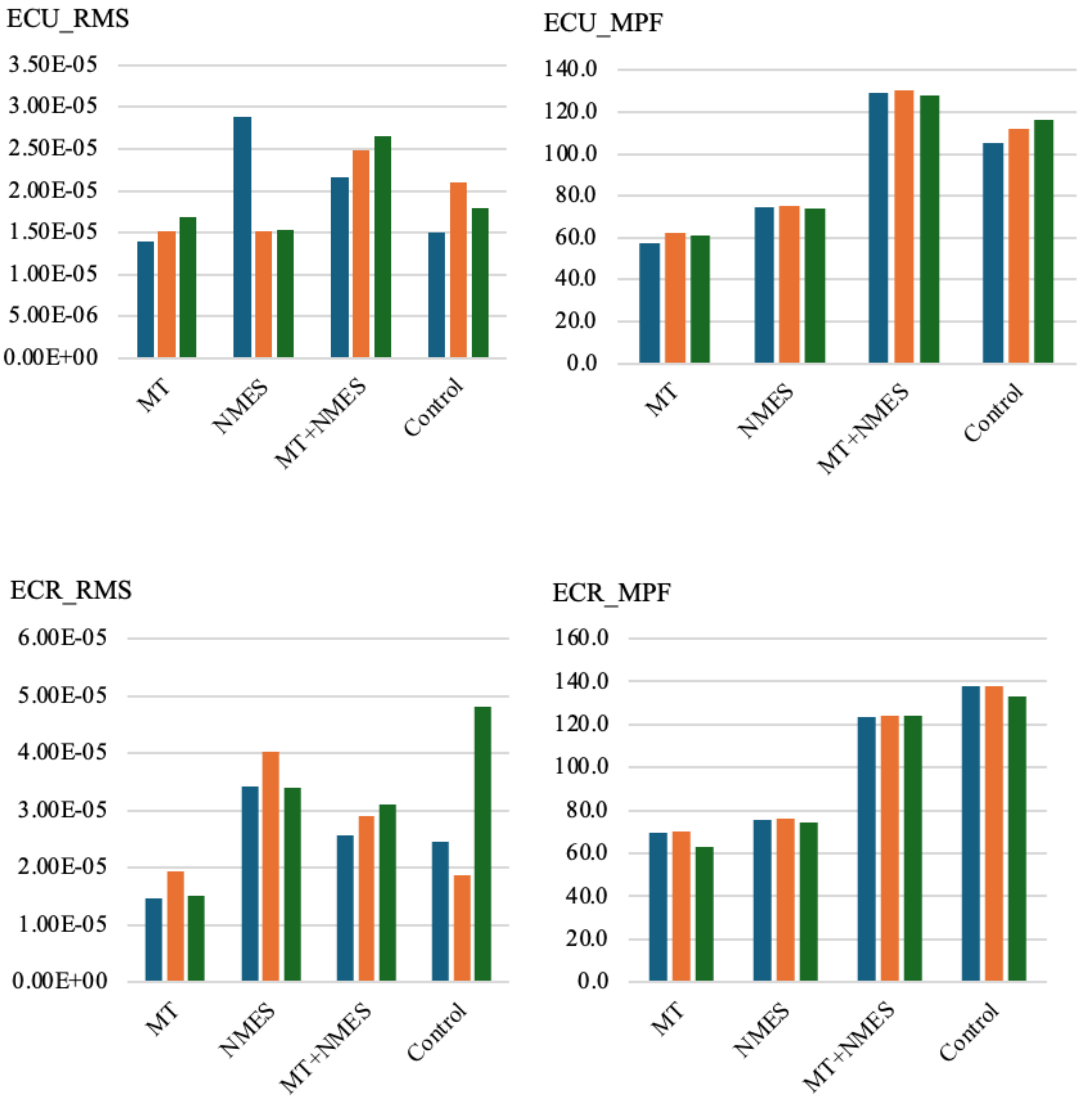

Fig. 14 RMS and MPF for ECU and ECR during wrist extension contractions on the affected side for the first (blue), second (orange), and third (green) contractions.

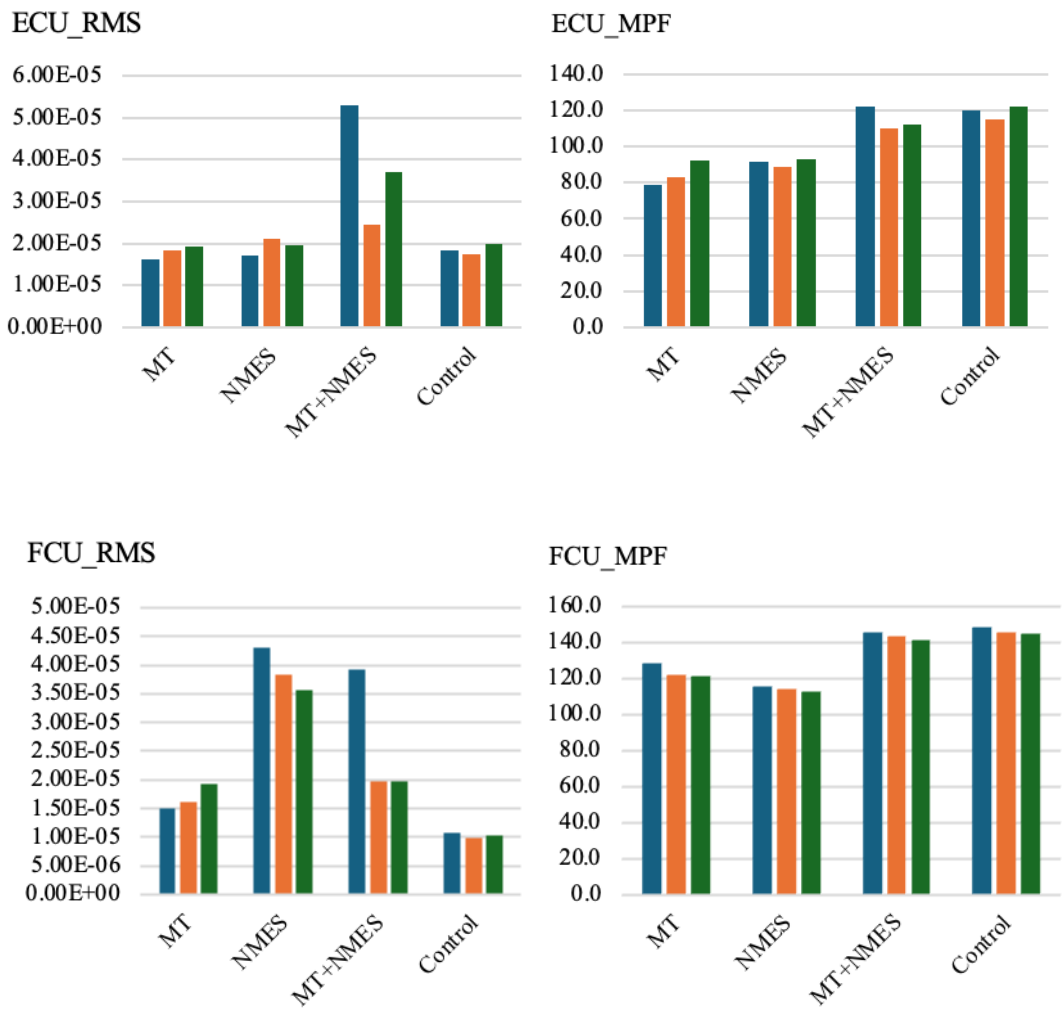

Fig. 15 RMS and MPF for ECU and FCU during ulnar deviation contractions on the affected side for the first (blue), second (orange), and third (green) contractions.

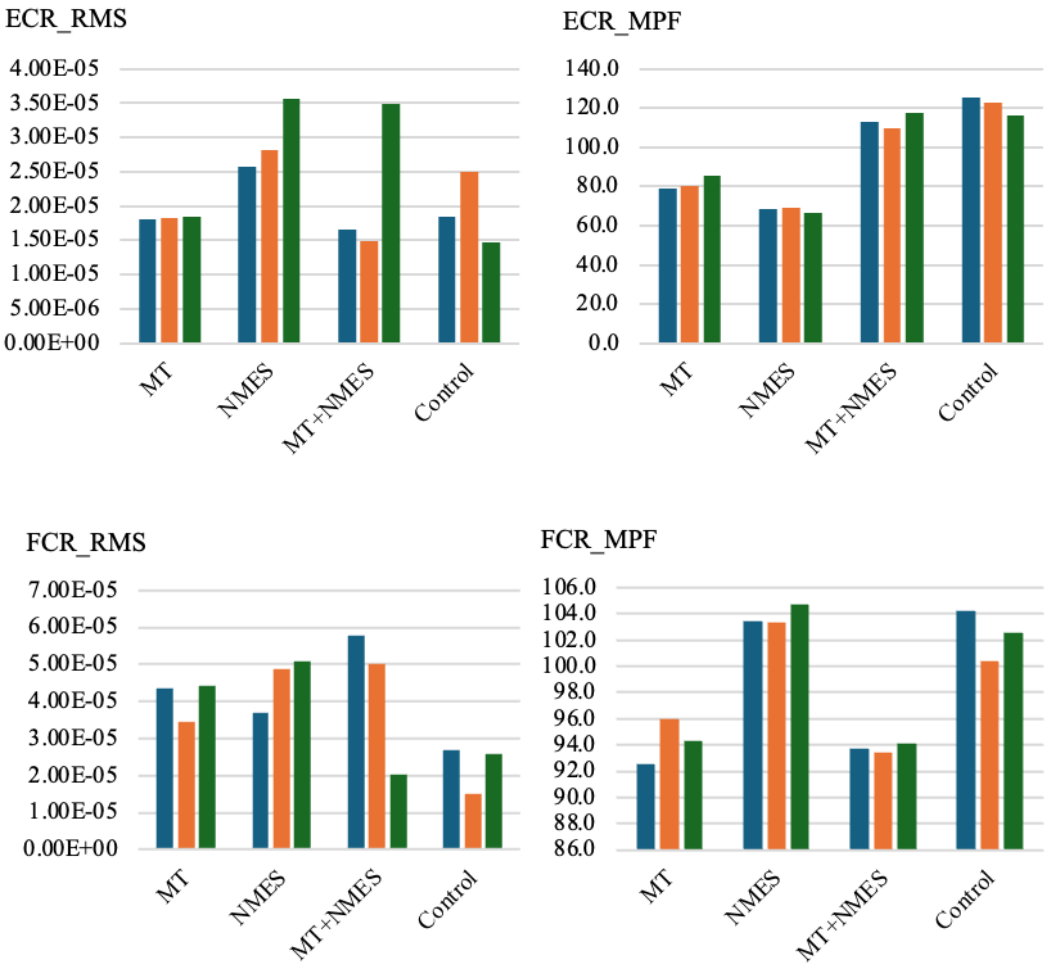

Fig. 16 RMS and MPF for ECR and FCR during radial deviation contractions on the affected side for the first (blue), second (orange), and third (green) contractions.

6.5 Discussion

This study was conducted concurrently with the 8-week and 12-week outcome assessment from Chapter 4. The aim of this study was to investigate the electromyographic activity for ECU, ECR, FCU, and FCR during ulnar deviation, wrist flexion, radial deviation, and wrist extension after DRF. This interim analysis presents a small sample of the data for the affected side at 8-weeks post-DRF.

During fatiguing contractions MPF decreases as the type II MUs that are recruited for a quick increase in force fatigue (155–158). An increase in RMS is representative of fatigue as MU recruitment increases in an attempt to maintain the contraction force (152–154). This pattern was not detectable in the data, but this is likely due to the study protocol. The protocol for this study had participants holding five second MVCs three times with breaks in between. With the short break between the MVCs, a comparable level of type II MU recruitment could take place at the start for the subsequent MVCs. A longer duration, submaximal contraction may be better to induce fatigue. With a 15 second (sec) contraction, the first 5 sec, middle 5 sec and final 5 sec could be compared. With a submaximal contraction it would be important to use a MVC to determine the target intensity for the submaximal contraction. Participants should be provided a visual gauge of the force they are producing so they have feedback while they aim to maintain the target force for the 15 sec.

There were a few limitations of this study that should be addressed for future investigations. The first is not measuring force production during the MVC. Without an external measure (e.g., force transducer) to establish if the force is maintained, changes in MPF and RMS may not be reflective of fatigue but rather changes in the force produced. Five second MVCs may be too short to induce a fatigue response, so a longer sustained contraction may be advantageous. Participants were able to take the time they needed between MVCs based on their symptoms. Location for electrode placement was determined through palpation of the muscles during active movement. A more precise method of identifying the muscle motor point could be used for electrode placement in the future.

6.6 Conclusion

This chapter presents an interim analysis of electromyographic activity for ECU, ECR, FCU, and FCR during ulnar deviation, wrist flexion, radial deviation, and wrist extension after DRF was conducted for individuals that participated in control, MT, NMES, or MT+NMES groups. This is the first study to compare EMG activity after engaging in interventions during the casting period for DRF. Changes in MPF and RMS were not detectable potentially due to the comparison between three 5-second MVCs. Future investigations may be better able to detect fatigue and MU recruitment patterns with comparison of the start, middle and end of a longer sustained contraction and including force measurements.

7 Grand Discussion

This thesis includes three studies that investigate the overarching theme of early intervention strategies for DRF. Particularly the use of MT, NMES, and MT+NMES during the immobilization period for DRF.

The second chapter is a scoping review that investigated the state of the literature for use of NMES during immobilization periods for musculoskeletal conditions. Six studies were included with a total of 127 participants. Parameters ranged from 40 minute to 8 hours sessions a day for interventions that lasted four to six weeks. NMES reduced the amount of quadriceps atrophy and strength loss following immobilization in four of the studies. The studies that have investigated NMES applications during immobilization are limited to anterior cruciate ligament repair and tibia fracture models from before 1989 where treatment with plaster cast immobilizations is now outdated.

The third chapter is a systematic review investigating the effects of MT on musculoskeletal conditions of the hand/wrist. Seven RCTs were included in this review with a total sample of 220 participants. Large effect sizes were reported in four studies, medium in three studies and small in five studies. One study was rated high quality, four moderate quality, and two low quality in the risk assessment. Five of the seven studies included active exercises of the affected side in the MT intervention groups. MT interventions were 20 to 75 minutes per session with 10 to 30 sessions. Pain, ROM, strength, and function were measured between three and 12-weeks after the injury or surgical intervention. Only one study investigated the use of MT during an immobilization period.

The fourth chapter was a feasibility RCT with four groups: MT, NMES, MT+NMES, and control. Participants completed interventions 10 minutes, three times a day, five days a week for the last three weeks of their casting period. Participants attended an initial visit 3-weeks post-DRF and three outcome assessments at 6-, 8-, and 12-weeks post-DRF. Pain, function, dexterity, ROM, and strength were measured at on-site visits. At the point of analysis, 19

participants were enrolled with a mean age of 58 (±14.3) years. Participants were all right-handed with 47% having fractured their dominant wrist. MT, NMES, MT+NMES interventions appear feasible with adherence to home interventions ranges between 89 to 100% and retention to outcome assessments was >80% for the intervention groups which exceed the threshold for the green zone. The recruitment rate was on average 5 participants per month and retention for the control group was 75% which land in the amber zone to proceed with changes. There were promising trends when assessing the limited efficacy testing data for the in-home interventions compared to existing literature for facilitating recovery. These findings are promising for the use of these early interventions, especially with no adverse events reported.

The fifth chapter shares the patient perspective of in-home MT, NMES, or MT+NMES interventions during the last three weeks of immobilization for DRF. The interviews took place after the 6-week follow up appointment the day their cast was removed. An interpretive descriptive approach was taken in the design and analysis for the interviews. Six themes were identified from the transcripts, which include accommodations for an easy commitment, time is limited, roadblocks to engagement, it's a win win situation, setting expectations and building confidence, and shock and awe. Participants being provided the equipment, valuing research, and having flexible schedules facilitated engagement in the program. Transportation and time were the main barriers discussed for intervention engagement. Participants reports support the practicality and acceptability of the interventions. Participants recommended these interventions become more widely available for all patients with DRFs.

The sixth chapter reports on a cohort study investigating whether the early interventions result in EMG changes. MPF and RMS were measured to assess type II MU recruitment strategies and fatigue in the ECU, ECR, FCU, and ECR during three, five-second MVCs for ulnar deviation, wrist flexion, radial deviation, and wrist extension. The interim analysis included in this thesis focuses on the 8-week data for the affected wrist. No differences in MPF or RMS were noted between MVCs for any group. A longer sustained contraction

may be more appropriate to assess fatigue from the start to end of the contraction in future investigations.

The aim of this thesis was to determine the feasibility of in-home MT, NMES, and MT+NMES interventions during the immobilization period for DRF. Chapter two and three highlight the gaps in using MT and NMES applications during immobilization for musculoskeletal conditions and this thesis outlines why conservatively managed DRFs are a great model to investigate this application.
Chapters 4 to 5 developed and investigated new in-home MT, NMES, and MT+NMES interventions applied during immobilization for DRF. The three studies discussed in Chapters 4 to 6 are all in active recruitment, data collection, and analysis. This thesis reports on 19 participants engaged in the program out of 72 participant goal for the feasibility RCT. Numbers will continue to change as new participants are recruited and data are collected at follow up visits. Conclusions to address the research questions are mostly based on descriptive analysis of means and commenting on trends. Additional recruitment is required to determine the feasibility of a full RCT.

Even at this interim analysis the in-home MT, NMES, and MT+NMES interventions the adherence and retention for the intervention groups meet the threshold for the green zone to proceed with the trial. The recruitment rate and retention for the control group resides in the amber zone to proceed with changes. Next steps are to continue with recruitment, data collection and analyses for the feasibility RCT, qualitative interviews, and EMG study. Once 72 participants are recruited, decisions to proceed, proceed with changes, or not proceed to a full RCT can be made.

7.1 Implications

This thesis was the first to investigate MT, NMES and MT+NMES interventions during the casting period for DRF. The interim analysis supports the feasibility of these early interventions during immobilization of DRF and there may be a potential benefit to outcomes for grip strength and function. Given the early stages

of investigation for this area of research the next step would be a full RCT if these trends continue with the full feasibility sample. Incorporating more centers in the recruitment would improve the accessibility of the interventions for more individuals that sustained DRFs without barriers for transportation. More centers would also facilitate recruitment for the full RCT.

In conclusion, the main accomplishment from the thesis was the development of in-home MT, NMES, and MT+NMES interventions to be applied during the casting period for DRF. The potential that these interventions could be applied in-home during the immobilization period for DRF could allow people to return to work, sports, and daily activities earlier. This could potentially reduce the financial burden for these individuals and improve quality of life. Continued investigation of these interventions is warranted to determine the feasibility of the interventions for a full RCT where between group comparisons can be made for the outcome measures.

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9 Appendices

Appendix A. Search strategy for Chapter 2: Application of neuromuscular electrical stimulation during immobilization of extremities for musculoskeletal conditions: A scoping review.

Search Strategy: ("electrical stimulation" OR "NMES" OR "neuromuscular electrical stimulation") AND ("musculoskeletal" OR "muscle" OR "bone" OR "fracture") AND ("immobilize" OR "immobilization" OR "cast" OR "splint")

Appendix B. PRISMA Checklist for Chapter 2: Application of neuromuscular electrical stimulation during immobilization of extremities for musculoskeletal conditions: A scoping review.

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3&4
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	4
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	4
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	4
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Supplemental Material 1
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	4

Data charting process	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	4
Critical appraisal of individual sources of evidence	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	4
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	4
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	4; Figure 1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	4 to 6; Table 1
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Supplemental Material 2
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Table 1
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	4 to 6
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	6&7
Limitations	20	Discuss the limitations of the scoping review process.	6&7
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	7&8
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	1

Appendix C. Quality Assessment for Chapter 2: Application of neuromuscular electrical stimulation during immobilization of extremities for musculoskeletal conditions: A scoping review.

Quality assessment of the included studies using the Joanna Briggs Institute (JBI) Critical Appraisal Tools for Cohort Studies.

	Arvidsson et al. (1986)	Eriksson & Häggmark (1979)	Gibson, Smith, & Rennie (1988)	Morrissey et al. (1985)	Sisk et al. (1987)	Wigerstad-Lossing et al. (1988)
Were the two groups similar and recruited from the same population?	yes	yes	unclear	yes	yes	yes
Were the exposures measured similarly to assign people to both exposed and unexposed groups?	yes	yes	unclear	yes	yes	yes
Was the exposure measured in a valid and reliable way?	yes	yes	yes	yes	yes	yes
Were confounding factors identified?	no	no	no	no	no	no

Were strategies to deal with confounding factors stated?	N/A	N/A	N/A	N/A	N/A	N/A
Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?	no	no	no	no	no	no
Were the outcomes measured in a valid and reliable way?	yes	yes	yes	yes	yes	yes
Was the follow up time reported and sufficient to be long enough for outcomes to occur?	yes	yes	yes	yes	yes	yes
Was follow up complete, and if not, were the reasons to loss to follow up described	no	yes	yes	yes	no	no

and explored?						
Were strategies to address incomplete follow up utilized?	unclear	N/A	N/A	N/A	unclear	unclear
Was appropriate statistical analysis used?	yes	yes	yes	yes	yes	yes
Overall Appraisal	include	include	include	include	include	include

Appendix D. Search strategy for Chapter 3: Effectiveness of mirror therapy to treat musculoskeletal injuries of the hand and wrist: a systematic review.

Search Strategy: ("distal radius fracture" OR "Colles fracture" OR "wrist fracture" OR “wrist” OR “hand”) AND ("mirror therapy" OR "mirror visual feedback" OR "mirror box therapy" OR "mirror imagery" OR "mirror exercise") AND ("pain" OR "function" OR "range of motion" OR "strength")

Appendix E. Semi-structured interview guide for Chapter 5: In-home mirror therapy and neuromuscular electrical stimulation interventions for distal radius fracture: a mixed methods feasibility study.

To get started, I am interested to hear about your understanding and overall impression of the interventions.

- What do you think the goal of the early interventions is?
    - *Probe: How would you describe the purpose of the program to others?*

Next, I'm going to ask you more specific questions. I am interested in both the positive and negative experiences you had with the program.

- Can you describe how you were recruited for the study and what led to your decision to participate.
    - *Probes: What was that like? How did it go? Did you have any hesitations? What made you want to sign up?*

- What was it like when you had your call with the research team and agreed to participate?
    - *Probes: What was that like? How did that go? What did you think of that? Did you have any hesitations? Were they addressed well in the call*

- Can you describe your experience with the initial session. Do you feel you were adequately supported with the intervention to be confident performing it at home alone?
    - *Probes: How satisfied were you with the instructions? What sorts of things did you need additional clarification with? How did it go? What did you think of that?*

- How did you find the on site visits?
    - *Probing: How was the time commitment? How did it go with parking?*

- What do you think could be improved with the on site visits?

- What do you feel was done well with the on site visits?

Now I'd like to ask you a few questions about the in-home intervention.

- Was the set up for the intervention manageable three times a day?
- Was the schedule for the intervention feasible with your schedule?
- What challenges did you experience with the in-home intervention?
- What worked well with the in-home intervention?

Now I'd like to ask you a few questions about the overall experience.

- What do you think are the main areas for improvement for the early intervention?
    - *Probe: What changes would you recommend for future implementation of the interventions?*

- What do you feel is the main benefit of participating in the early intervention?
    - *Probes: Were there any opportunities came out of your participation in the program? If so, what were they?*

- What drawbacks, if any, do you think exist from participating in the early intervention?
    - *Probe: Can you explain these?*

In closing: Is there anything else you think is important to note that we haven't covered?

Appendix F. Ethics Approval for Chapters 4 to 7.

Western Research

Date: 10 July 2023

To: Dr. Joy MacDermid

Project ID: 120275

Review Reference: 2023-120275-81380

Study Title: Early Neuromuscular Stimulation and Mirror Therapy Interventions to Prevent Functional Loss During Immobilization of Distal Radius Fracture

Application Type: HSREB Initial Application

Review Type: Full Board

Meeting Date / Full Board Reporting Date: 18/July/2023

Date Approval Issued: 10/Jul/2023 09:20

REB Approval Expiry Date: 10/Jul/2024

Dear Dr. Joy MacDermid

The Western University Health Science Research Ethics Board (HSREB) has reviewed and approved the above mentioned study as described in the WREM application form, as of the HSREB Initial Approval Date noted above. This research study is to be conducted by the investigator noted above. **All other required institutional approvals and mandated training must also be obtained prior to the conduct of the study**.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Protocol CLEAN	Protocol	03/May/2023	2
Scripts for Consent CLEAN	Telephone Script	21/May/2023	2
Recruitment Checklist CLEAN	Telephone Script	20/Jun/2023	2
Semi-Structured Interview Guide V1 CLEAN	Interview Guide	20/Jun/2023	1
Session Trackers V3 CLEAN	Other Data Collection Instruments	26/Jun/2023	3
NMES Instructions V3 CLEAN	Other Participant Material(s)	26/Jun/2023	3
MT Instructions V3 CLEAN	Other Participant Material(s)	26/Jun/2023	3
MT and NMES Instructions V3 CLEAN	Other Participant Material(s)	26/Jun/2023	3
Challenge Reporting Form CLEAN	Other Data Collection Instruments	26/Jun/2023	1
Adverse Event Reporting Form V1 CLEAN	Other Data Collection Instruments	26/Jun/2023	1
Recruitment Package V1 CLEAN	Other Data Collection Instruments	26/Jun/2023	1
Study Procedures Manual V4 CLEAN	Protocol	28/Jun/2023	4
Questionnaires V4 CLEAN	Paper Survey	28/Jun/2023	4
Protocols and Case Report Form V2 CLEAN	Other Data Collection Instruments	28/Jun/2023	2
Letter of Invitation V4 CLEAN	Written Consent/Assent	28/Jun/2023	4

Documents Acknowledged:

Document Name	Document Type	Document Date	Document Version
CIHR Reviewer Comments	Scientific Review Documents		

Document Name	Document Type	Document Date	Document Version
Rationale References	References		
Budget CLEAN	Study budget	20/Jun/2023	2

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Electronically signed by:

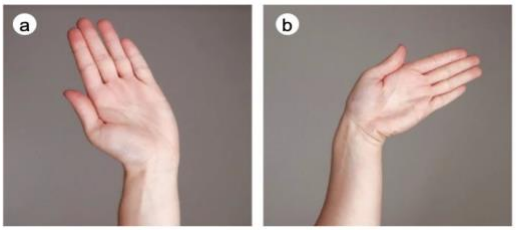
Patricia Sargeant, Ethics Officer ([redacted]) on behalf of Dr. Naveen Poonai, HSREB Chair, 10/Jul/2023 09:20

Reason: I am approving this document

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations, See Electronic System Compliance Review)

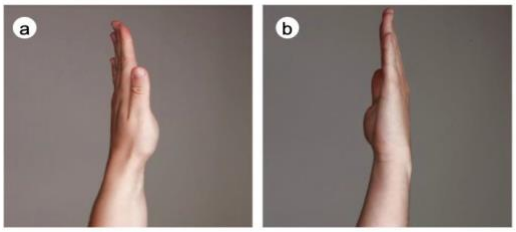
Appendix G. Mirror therapy exercises provided in the MT and MT+NMES intervention packages.

Perform each exercise 10 times. Then start at the beginning and do a second set of 10 repetitions for each exercise.



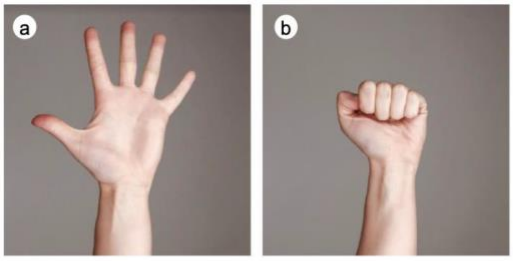
Tip your wrist side to side with your fingers extended. Each rep should take 6 seconds (sec).

a) 2 sec to bring your thumb towards your body. Coordinate this with feeling the stimulation on the *outside* of the forearm. Pause for 1 sec here.
b) 2 sec to push your little finger away from your body. Coordinate this with feeling the stimulation on the *inside* of the forearm. Pause 1 sec here.



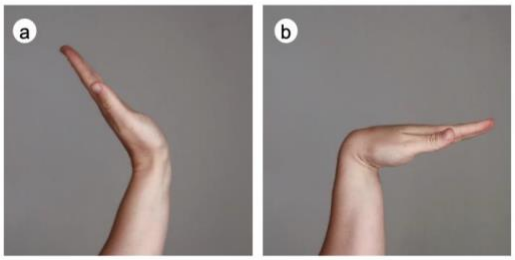
Turn your palm away and towards your body with your fingers straight. Each rep should take 6 sec.

a) 2 sec to extend your wrist back. Coordinate this with feeling the stimulation on the *outside* of the forearm. Pause for 1 sec here.
b) 2 sec to flex your wrist forward. Coordinate this with feeling the stimulation on the *inside* of the forearm Pause 1 sec here.



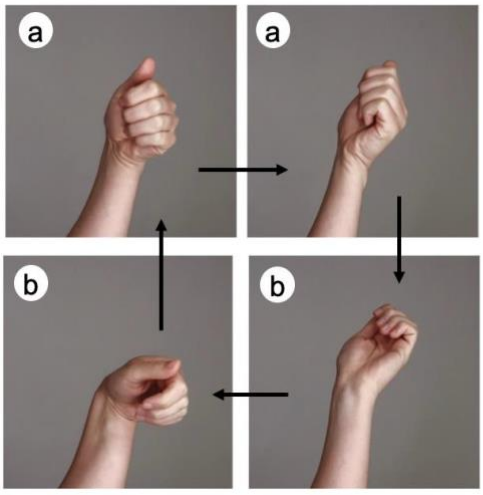
Open and close your hand. Each rep should take 6 seconds (sec).

a) 2 sec to open your hand straighten and spread your fingers apart. Coordinate this with feeling the stimulation on the *outside* of the forearm. Pause for 1 sec here.
b) 2 sec to curl up your fingers to make a fist. Coordinate this with feeling the stimulation on the *inside* of the forearm. Pause 1 sec here.



Extend and flex the wrist with your fingers extended. Each rep should take 6 sec.

a) 2 sec to extend your wrist back. Coordinate this with feeling the stimulation on the *outside* of the forearm. Pause for 1 sec here.
b) 2 sec to flex your wrist forward. Coordinate this with feeling the stimulation on the *inside* of the forearm. Pause 1 sec here.



Do wrist circles. Each rep should take 6 seconds (sec).

a) 3 sec to bring your hand back. Coordinate this with feeling the stimulation on the *outside* of the forearm.
b) 3 sec to bring your hand down towards your forearm. Coordinate this with feeling the stimulation on the *inside* of the forearm

Repeat 6 times in each direction

Appendix H. Questionnaire booklet. (V4 – 28/06/23).

PATIENT RATED WRIST EVALUATION

*The questions below will help us understand how much difficulty you have had with your wrist in the past week. You will be describing your **average** wrist symptoms **over the past week** on a scale of 0 to 10.* Please provide an answer for **ALL** questions. If you did not perform an activity, please **ESTIMATE** the pain or difficulty you would expect. If you have **never** performed the activity, you may leave it blank.

PAIN	
Rate the **average** amount of pain in your wrist over the past week by circling the number that best describes your pain on a scale from 0-10. A zero **(0)** means that you **did not** have any pain and a **ten (10)** means that you had the **worst pain you have ever experienced** or that **you could not do the activity because of pain.**	
At rest	0 1 2 3 4 5 6 7 8 9 10
When doing a task with a repeated wrist movement	0 1 2 3 4 5 6 7 8 9 10
When lifting a heavy object	0 1 2 3 4 5 6 7 8 9 10
When it is at its worst	0 1 2 3 4 5 6 7 8 9 10
How often do you have pain?	0 1 2 3 4 5 6 7 8 9 10 Never Always

FUNCTION	
A. SPECIFIC ACTIVITIES Rate the **amount of difficulty** you experienced performing each of the items listed below - over the past week, by circling the number that describes your difficulty on a scale of 0-10. A **zero** (0) means you did not experience any difficulty and a **ten** (10) means it was so difficult you were unable to do it at all.	
Turn a door knob using my affected hand	0 1 2 3 4 5 6 7 8 9 10
Cut meat using a knife in my affected hand	0 1 2 3 4 5 6 7 8 9 10
Fasten buttons on my shirt	0 1 2 3 4 5 6 7 8 9 10

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Use my affected hand to push up from a chair	0 1 2 3 4 5 6 7 8 9 10
Carry a 10lb object in my affected hand	0 1 2 3 4 5 6 7 8 9 10
Use bathroom tissue with my affected hand	0 1 2 3 4 5 6 7 8 9 10
B. USUAL ACTIVITIES Rate the **amount of difficulty** you experienced performing your **usual** activities in each of the areas listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. By "usual activities", we mean the activities you performed **before** you started having a problem with your wrist. A **zero** (0) means that you did not experience any difficulty and a **ten** (10) means it was so difficult you were unable to do any of your usual activities.	
Personal care activities (dressing, washing)	0 1 2 3 4 5 6 7 8 9 10
Household work (cleaning, maintenance)	0 1 2 3 4 5 6 7 8 9 10
Work (your job or usual everyday work)	0 1 2 3 4 5 6 7 8 9 10
Recreational activities	0 1 2 3 4 5 6 7 8 9 10

Study ID#: _____ Date: _____

EQ-5D HEALTH QUESTIONNAIRE

By placing a tick in **one** box in each group below, indicate which statements best describes your health state **TODAY**.

Mobility ☐ I have no problems walking about ☐ I have slight problems walking about ☐ I have moderate problems walking about ☐ I have severe problems walking about ☐ I am unable to walk about **Usual Activities** (e.g. work, study, house work, family or leisure activities) ☐ I have no problems with performing my usual activities ☐ I have slight problems with performing my usual activities ☐ I have moderate problems with performing my usual activities ☐ I have severe problems with performing my usual activities ☐ I am unable to perform my usual activities	**Self-Care** ☐ I have no problems with self-care ☐ I have slight problems with self-care ☐ I have moderate problems with self-care ☐ I have severe problems with self-care ☐ I am unable to wash or dress myself **Pain/discomfort** ☐ I have no pain or discomfort ☐ I have slight pain or discomfort ☐ I have moderate pain or discomfort ☐ I have severe pain or discomfort ☐ I have extreme pain or discomfort **Anxiety/Depression** ☐ I am not anxious or depressed ☐ I am slightly anxious or depressed ☐ I am moderately anxious or depressed ☐ I am severely anxious or depressed ☐ I am extremely anxious or depressed

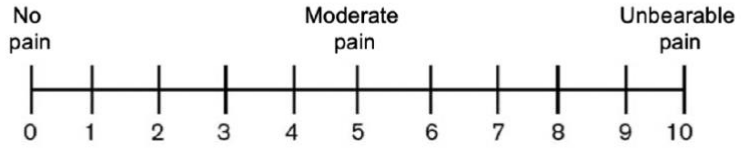
Please mark a slash ("X") on the scale to indicate how your health is TODAY

VR 1 05 JAN 2021

V4 – 28/06/23

PAIN SCALE

0 – 10 VAS Numeric Pain Distress Scale

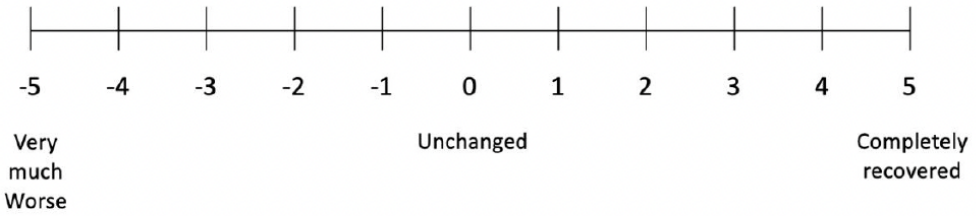


	Rating
How bad was your pain when at <u>rest</u> in the last week, on average? ***"On a scale of 0 to 10*** *<show/refer to scale>* ***how bad was your pain when at rest this past week, on average? If you had no pain at rest, choose zero."***	____ / 10
How bad was your pain during movement in the last week, on average? ***"On a scale of 0 to 10*** *<show/refer to scale>* ***how bad was your pain during movement this past week, on average? If you had no pain during movement, choose zero."***	____ / 10

GLOBAL RATING OF CHANGE SCALE (GRC)

The following rating scale allows us to review the overall outcome of your condition with the care provided by us. It allows us to review your outcome, which helps guide our treatment to better serve our patients in the future. The Global Rating of Change (GRC) has been well documented and extensively used in research as an outcome measure as well as to compare outcome measures.

Please rate the overall condition of your injured elbow/wrist FROM THE TIME THAT YOU BEGAN TREATMENT UNTIL NOW (**Circle only one**):



From: Kamper SJ, Maher CG, Mackay G. Global rating of change scales: Review of strengths and weaknesses and considerations for design. The Journal of Manual & Manipulative Therapy.2009;17(3):163.

SINGLE ASSESSMENT NUMERIC EVALUATION (SANE)

On a scale from 0 to 100, how would you rate your wrist today (with 100 being normal)?

_____

From: Williams GN, Taylor DC, Gangel TJ, Uhorchak JM, Arciero RA. Comparison of the single assessment numeric evaluation method and the Lysholm score. Clin Orthop. 2000; 373:184-192.

Appendix I. Within group mean difference from initial to 12-week visit, 80% CI, and standard deviation for ROM as a percentage of the unaffected side.

	MT			**NMES**			**MT+NMES**			**Control**		
	Mean Diff.	80% CI (Lower, Upper)	SD	Mean Diff.	80% CI (Lower, Upper)	SD	Mean Diff.	80% CI (Lower, Upper)	SD	Mean Diff.	80% CI (Lower, Upper)	SD
Wrist Flexion	-43.3	-61.5, -25.05	22.2	-23.0	-42.46, -3.54	23.8	-34.0	-74.09, 6.09	48.9	-12.3	-30.7, 6.02	16.9
Wrist Extension	-35.0	-58.69, -11.31	28.9	-33.5	-43.38, -23.62	12.1	-25.8	-56.06, 4.56	37.0	-27.0	-64.09, 10.09	34.1
Ulnar Deviation	-19.0	-45.69, 7.69	32.6	-32.3	-67.38, 2.88	42.9	-35.8	-54.8, -16.67	23.3	2.0	-35.67, 39.67	34.6
Radial Deviation	25.3	-29.76, 80.26	67.2	-36.8	-46.45, -27.05	11.8	-12.0	-36.34, 12.34	29.7	-49.7	-103.56, 4.22	49.5
Supination	-63.0	-103.54, -22.46	49.5	-52.8	.-83.28, -22.23	32.3	-20.3	-44.47, 3.97	29.6	-30.3	-40.91, -19.76	9.7
Pronation	-14.0	-33.79, 5.79	24.2	-24.5	-56.74, 7.74	39.4	-21.3	-41.37, -1.13	24.6	-0.7	-42.79, 41.46	38.7
Thumb Extension	-3.8	-18.50, 10.99	18.0	-12.8	-29.15, 3.65	20.0	-7.5	-29.85, 14.85	27.3	0	-11.47, 11.47	10.5

Note: Individuals that missed the 12-week visits are excluded from these results. Mean Diff. = within group mean difference, MT = mirror therapy, NMES = neuromuscular electrical stimulation, CI = confidence intervals, SD = standard deviation

10 Curriculum Vitae

Name:	Stephanie Reischl
Post-secondary Education and Degrees:	PhD in Rehabiltiation Sciences (Physical Therapy) Collaborative Specialization in Musculoskeletal Health Research The University of Western Ontario 2019-2024 Master of Physical Therapy The University of Western Ontario 2021-2023 Diploma in Massage Therapy Ontario College of Health and Technology 2019-2020 Master of Science in Applied Health Sciences Kinesiology Brock University 2016-2018 Bachelor of Science in Neuroscience Brock University 2011-2016
Professional Certifications:	Physical Therapy (#22263) College of Physiotherapists of Ontario 2024-present Registered Massage Therapist (B-1568) College of Massage Therapists of Ontario 2021-present
Honours and Awards:	Barbara Edwardson Orthopaedic Award University of Western Ontario 2023 National Orthopaedic Division Annual Student Award University of Western Ontario 2023 Kathy Obright Graduate Award in Physical Therapy University of Western Ontario 2022

The Chronic Pain Network – Knowledge Translation Award
The University of Western Ontario
2021-2022

Canada Institutes of Health Research Doctoral Award: Frederick Banting and Charles Best Canada Graduate Scholarship
The University of Western Ontario
2022

CMHR Transdisciplinary Bone & Joint Training Award
The University of Western Ontario
2020

Ontario Graduate Scholarship
Brock University
2017-2018

Related Work Experience:

Lab Facilitator for the School of Physical Therapy
The University of Western Ontario
2023-present

Physical Therapist
CREW Clinic, London, ON
2024-present

Registered Massage Therapist
Legacy Health and Performance, St. Catharines, ON
2021-present

Co-Instructor: Perspectives in Knowledge Translation HS 9623B
The University of Western Ontario
Summer 2024

Guest Lecturer: HS 3300 Special Senses: Hearing
The University of Western Ontario
2024

Lead Facilitator for PT 9112 Motor Control Lab
The University of Western Ontario
2017-2018

Teaching Assistant: Social Determinants of Health HS 1002B
The University of Western Ontario
2020 & 2021

Teaching Assistant: Research Methods – Critical Appraisal of Healthcare Literautre PT 9600/APPL 9013
The University of Western Ontario
2020

Teaching Assistant: Biomechanics KINE 3P10
Brock University
2016 & 2017

Teaching Assistant: Motor Control PEKN 3P94
Brock University
2016 & 2017

Knowledge Translation:

Reischl, S.A. Lay Summary of *Early Neuromuscular Stimulation and Mirror Therapy Interventions to Prevent Functional Loss During Immobilization of Distal Radius Fractures* for Inspiring Minds Showcase through Western Libraries *https://ir.lib.uwo.ca/exhibit/inspiring-minds-showcase/why-wait-early-rehabilitation-strategies-during-casting-of-broken-wrists-to-improve-recovery/*

Reischl, S.A. & Furtado, R. Patient engagement – the forgotten puzzle piece to creating patient reported outcome measures. rehabINK. *https://rehabinkmag.com/2022/06/16/patient-engagement-the-forgotten-puzzle-piece-to-creating-patient-reported-outcome-measures/*

Publications:

Reischl, S.A., Ziebart, C., MacDermid, J.C., Grewal, R., Schabrun, S.M., & Trejos, A.L. Application of neuromuscular electrical stimulation during immobilization of extremities for musculoskeletal conditions: A scoping review. In press. *Journal of Bodywork & Movement Therapies.* https://doi.org/10.1016/j.jbmt.2024.08.010

Reischl, S.A., Ziebart, C., Johnston, Z., Ma, J., Pham, D., Salloum, J.F., Sithganesan, M., Wikkerink, S., Munro, K., & MacDermid, J.C. Patient experience of stiffness with knee osteoarthritis: An interpretative description study. *Musculoskeletal Care, 22(3), e1922*. https://doi.org/10.1002/msc.1922

Nazari, G., Bobos, P., Lu, S., **Reischl, S.A.**, Sharma, S. Le, C.Y., Vader, K., Held, N. & MacDermid, J.C. (2022). Effectiveness of instrument-assisted soft tissue mobilization for the management of upper body, lower body, and spinal conditions. An updated systematic review with meta-analyses. Disability and Rehabilitation. DOI: 10.1080/09638288.2022.2070288

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Nazari, G., Bobos, P., Lu, Z., **Reischl, S.**, & MacDermid, J. C. (2020). Psychometric properties of Patient-Specific Functional Scale in patients with upper extremity disorders. A systematic review. *Disability and rehabilitation*, 1–10. Advance online publication. https://doi.org/10.1080/09638288.2020.1851784

Reischl, S., Dabbagh, A., & MacDermid, J. C. (2020). Appraisal of Clinical Practice Guideline: OPTIMa revised recommendations for non-pharmacological management of persistent headaches associated with neck pain. *Journal of physiotherapy*, *66*(3), 201. https://doi.org/10.1016/j.jphys.2020.05.009

Reischl, S., & MacDermid, J. C. (2020). Appraisal of Clinical Practice Guideline: Subacromial decompression surgery for adults with shoulder pain. *Journal of physiotherapy*, *66*(3), 201. https://doi.org/10.1016/j.jphys.2020.05.008

Reischl, S. A., Raza, S. Z., Adkin, A. L., Patterson, J. T., & Tokuno, C. D. (2019). Examining changes in corticospinal excitability and balance performance in response to social-comparative feedback. *Gait & posture*, *73*, 14–19. https://doi.org/10.1016/j.gaitpost.2019.07.129

Publications – *In progress*:

Reischl, S.A. & MacDermid, J.C. Comparative analysis of health-related quality of life after distal radius fracture and ulnar neuropathy: A secondary analysis. Accepted pending approval of minor revisions with *Journal of Hand Therapy*.

Reischl, S.A., Grewal, R., Schabrun, S.M., Trejos, A.L., & MacDermid, J.C. Feasibility of in-home neuromuscular electrical stimulation and mirror therapy applications as early interventions for distal radius fracture: A randomized control trial protocol. Under review with *BMJ Open.*

Reischl, S.A., Furtado, R., MacDermid, J.C. Grewal, R., Schabrun, S.M., & Trejos, A.L., Effectiveness of mirror therapy interventions to treat orthopaedic injuries of the hand and wrist: a systematic review. Under review with *Journal of Hand Therapy.*

Reischl, S.A., MacDermid, J.C., Grewal, R., Schabrun, S.M., & Trejos, A.L. In-home mirror therapy and neuromuscular electrical stimulation interventions for distal radius fracture: a mixed methods feasibility study. Under review with *Physical Therapy & Rehabilitation Journal.*

Reischl, S.A., Atrana, L., Chana, J., Dirvena, K., Lea, L., Parka, A., Ziebart, C., & MacDermid, J.C. Beyond morning stiffness: A qualitative study on joint stiffness and hand osteoarthritis. In preparation to submit to *Physiotherapy Canada.*