Focal Muscle Vibration for Stroke Rehabilitation: A Review of Vibration Parameters and Protocols

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Featured Application: This review summarized the focal muscle vibration devices, parameters, and protocols that have been used for stroke rehabilitation. The review discussed the application of wearable focal muscle vibration technology for sustainable stroke rehabilitation and suggested future research on the relationship between vibration frequency, amplitude, treatment protocol, and outcome measures for optimized and individualized intervention in stroke.

Abstract: In this review, we present a narrative synthesis of studies on the use of focal muscle vibration (FMV) in stroke rehabilitation with a focus on vibration device, parameters, and protocols. A search was conducted via PubMed, SCOPUS, PEDro, REHABDATA, and Web of Science using the keywords “stroke and focal vibration” or “focal muscle vibration”. Inclusion and exclusion criteria to select the articles were determined. Twenty-two articles involving FMV and stroke were included in this review. Eight different vibration devices were used in the 19 articles that reported the vibration apparatuses. The vibration frequencies ranged from 30 Hz to 300 Hz with amplitudes ranging from 0.01 mm to 2 mm. The vibration treatment frequency ranged from a single treatment to 5 days/week. The session duration ranged from 14 s to 60 min/session with a duration of a single treatment to eight weeks. Twenty different muscles were targeted with 37 different outcome measures used to assess the effects of FMV. The clinical applications of FMV were not confirmed based on available evidence. More research is needed to improve the FMV technology, guide the selection of vibration parameters, optimize the vibration dosage, and develop standardized protocols for FMV therapy in patients with stroke.

Keywords: focal muscle vibration; FMV; stroke; vibration frequency; vibration amplitude; vibration duration; vibration device(s)

1. Introduction

Stroke is the second leading cause of death and one of the most common causes of adult-onset disability worldwide. According to a recent study, 26% of individuals with stroke have a disability in activities of daily living (ADL), and 50% have reduced mobility due to hemiparesis [1]. The post-stroke disruption of the sensory system plays an important role in motor dysfunction of the hemiparetic limb [2]. Loss of proprioception impairing corrections to movement errors and loss of tactile sensation are common consequences of stroke and affect control of limb motion [3]. Another major problem affecting nearly 20–30% of stroke survivors is gait disorders [4]. These disorders further increase the
risk of falls and loss of balance, reducing patients’ social participation. According to National Stroke Association’s post-stroke recovery guidelines, only 10% of stroke survivors recover almost completely; 25% recover with minor impairments; 40% experience moderate to severe impairments requiring special care; 10% require care in a nursing home or other long-term care facility; and 15% die shortly after the stroke [5]. While numerous therapies have been developed over the last 10 years to treat acute ischemic stroke, the stark reality remains that 95% of these patients continue intervention in the chronic stage and go on to live with significant disability for many years.

Because of the complexity of a stroke, various approaches to chronic stroke rehabilitation, such as facilitation technique [6,7], functional electric stimulation (FES) [8,9], transcutaneous electrical stimulation (TENS) [10,11], electromyography (EMG) biofeedback [12], exercise [13,14], physical and occupational therapy [15,16], robotics [17,18], and virtual reality [19,20], have been studied to help functional recovery from hemiplegia due to brain damage. The limitations of the aforementioned intervention strategies are their sustainability due to one or more of these challenges: the requirement of trained and licensed professionals to administer the right dose to ensure safety; lack of precision and accuracy of intervention; lack of consensus among the findings; lack of sufficient evidence to establish the effectiveness of the intervention strategies; awareness of and access to existing intervention strategies; the cost of administration; and other similar disparities [21–24]. One intervention strategy that has the potential for sustainable stroke rehabilitation is the use of mechanical vibration as a therapeutic intervention known as vibration therapy (VT) [25–29]. According to Murillo et al. (2014), VT as an intervention in rehabilitation can be dated back to 1969, when Hagbarth and Eklund observed tonic vibration reflex (TVR) in which the application of vibratory stimulus resulted in agonist muscle contraction and antagonist relaxation. Hagbarth and Eklund then used this observation as a basis to use vibration to decrease muscle spasticity in individuals with stroke [28,29].

There are two types of VT: whole body vibration (WBV), in which mechanical vibrations are transmitted from the feet to the rest of the body using a vibrating platform, and focal muscle vibration (FMV), where mechanical vibrations are applied to a localized point in muscles, generally the muscle belly or the tendon on the affected/paretic side. The potential mechanism behind using vibration as an intervention in the treatment of motor disorders in patients is that vibration stimulates the primary muscle spindle endings, causing Ia afferent impulses to be conducted to alpha motor neurons and Ia inhibitory interneurons in the spinal cord. This afferent pathway produces involuntary contraction in the vibrated muscle (that is, a tonic vibration reflex, TVR) and inhibits the antagonist muscle [30,31]. The effect of VT on the human body depends on the characteristics of the vibration applied, such as type of vibration (vertical, horizontal, or multidirectional), frequency, amplitude, and the protocol [27]. The effects also depend on the characteristics of the person, such as age, gender, and health condition [26,27].

WBV has been widely studied, and the evidence agrees on the pros and the cons of its application in patients with stroke [32–40]. The application of FMV for patients with stroke has been less widely studied [28,29]. Only one review specifically focused on FMV in stroke [28]. The authors summarized eight studies and concluded that FMV showed some evidence in reducing hemiplegic upper extremity spasticity in patients with stroke, and additional randomized controlled trials were needed to study the effects on FMV on spasticity in individuals with stroke [28].

Multiple studies have been conducted on the use of FMV for stroke rehabilitation in upper and lower limb impairments. These studies showed some improvements in functionality and reduction of muscle spasticity. However, there is a lack of consensus regarding its clinical application. The other gaps include the lack of protocol (frequency and amplitude of vibration, number of days and duration of intervention and overall study, etc.), standardized outcome measures, and recommended vibration devices. The purpose of this review was to focus on the current FMV devices in use, the vibration parameters applied, and protocols of FMV therapy and outcome measurements in post-stroke rehabilitation.
2. Materials and Methods

2.1. Search Strategy

A search was conducted in the following electronic databases: PubMed, SCOPUS, PEDro, REHABDATA, and Web of Science. The key search terms were (focal muscle vibration OR fmv OR vibration OR focal vibration OR focal-muscle-vibration OR segmental muscle vibration OR localized mechanical vibration) AND (neurological OR central nervous system OR nervous system OR diseases OR disorders OR spinal cord OR brain OR cerebral OR neurological manifestations) AND (motor OR motor impairments OR physical OR impairment OR activity OR disability OR function OR movement). No time restraint was applied to the literature search that was finished in July 2020.

2.2. Study Selection

Studies were included if they were written in English, treated patients who were diagnosed with stroke, and used focal muscle vibration as the primary intervention for rehabilitation. Studies were excluded if they did not use focal vibration as the main intervention, treated multiple diagnoses, did not have at least one motor outcome, or did not report any parameters for the application of vibration.

2.3. Data Extraction

All authors (H.W., R.C., J.R., M.G.) searched the different databases for relevant publications using the aforementioned keywords. The searched articles were screened by authors H.W. and R.C. for relevance, followed by a title and abstract review through a discussion between H.W. and R.C. Then, a full text review by all four authors was performed based on a pre-developed data extraction form. Two of the authors (R.C. and M.G.) developed an Excel document with the following data extracted: participant characteristics (number, gender, mean age), vibration devices, vibration parameters (frequency and amplitude), protocols (dosage and duration), region of application of vibration, outcome measures, and results. All four authors made the final decision on articles to be included in this review and discussed the studies with a focus on vibration parameters and protocols.

3. Results

3.1. Search Results

The review process is shown in Figure 1. The search yielded 411 (PubMed 147 articles, SCOPUS 56 articles, PEDro 13 articles, REHABDATA 12 articles, and Web of Science 183 articles) results. After removing duplicates, 177 articles were reviewed. Of these articles, about 53 were selected for review of titles and abstracts based on relevance, language, and intervention. Ten out of the 53 papers were excluded based on relevance and patient diagnoses. The remaining 43 papers were selected for the full text review. This list was then narrowed down to a final list of 22 papers.
Figure 1. Summary of literature review process.

Of the 22 studies included in this review, four articles targeted only the lower extremity [41–44], 17 studies targeted only the upper extremity [45–61], and one targeted both upper and lower extremities [62]. There were 14 randomized controlled trials (RCT) [42,43,47,49–53,55,57,58,60–62], seven quasi-experimental design, [41,44–46,48,54,59], and one single subject design [56]. The details of each included study are summarized below in Table 1. The vibration device used, vibration parameter, and protocols are summarized in Table 2.
| Article and No. | Design and Participant Characteristics | Outcome Measure | Results |
|----------------|----------------------------------------|-----------------|---------|
| P1. Kawahira et al. 2004 | Design: Single group pre-post Subjects (n): 13 Age: 58.2 ± 9.7 Stroke type: Chronic Hemiplegia, R/L (n): 9/4 Intervention: FMV | Gait speed | Gait speed improved; Time to walk 10 m: Pre: 13.7 ± 4.0 s Post: 12.8 ± 3.9 s |
| P2. Noma et al. 2009 | Design: Single group pre-post Subjects (n): 14 Age: 57.3 ± 19.1 Stroke type: Acute Hemiplegia, R/L (n): 8/6 Intervention: FMV | MAS (Modified Ashworth Scale) EMG (Electromyograph) | MAS pre, immediately after FMV, and 30 min post: Biceps brachii: 2.1 ± 1.0; 0.2 ± 0.4; 1 ± 1 Wrist flexor: 2.5 ± 0.8; 0.3 ± 0.6; 1.4 ± 0.9 Finger flexors: 2.5 ± 0.6; 0.2 ± 0.4; 1.1 ± 1 F-wave amplitude pre, immediately after FMV, and every 5 min post: 593 ± 255, 417 ± 282, 360 ± 234, 366 ± 260, 368 ± 249, 351 ± 238, 366 ± 205, 367 ± 202 mV F/M ratios pre, immediately after FMV, and every 5 min post: 4.9 ± 1.8, 3.6 ± 2.5, 3.1 ± 2.0, 3.1 ± 2.2, 3.1 ± 2.1, 3.0 ± 2.2, 3.1 ± 1.8, 3.1 ± 1.7% |
| P3. Paolini et al. 2010 | Design: RCT (Randomized Control Trial) Subjects (n): 44; EG (Experimental Group) 22, CG (Control Group) 22 Age: EG 59.5 ± 13.3 CG 62.5 ± 9.5 Stroke type: Chronic Hemiplegia, R/L (n): 23/21 Intervention: EG- FMV and PT, CG- PT (Physical Therapy) | Gait EMG (Electromyograph) KE (Kinematic Evaluation) | EG: Improvement in Gait Toe-off on paretic side (%): 62.6 ± 5.8, 59.6 ± 5.5 Stride length on normal side: 0.71 ± 0.20, 0.82 ± 0.18 Stride length on paretic side: 0.70 ± 0.19, 0.79 ± 0.17 Swing velocity normal side: 1.32 ± 0.34, 1.53 ± 0.39 Gait speed: 0.44 ± 0.13, 0.53 ± 0.13 |
| P4. Liepert et al. 2010 | Design: Single group pre-post Subjects (n): 10 Age: 57 ± 13 Stroke type: Chronic Hemiplegia, R/L (n): 8/2 Intervention: FMV | BBT (Box and Block Test) CSP (Cortical Silent Period) | BBT 20% less time to complete CSP Significant prolongation in the affected and the healthy flexor carpi radialis muscle. The duration of the CSP was not different between affected and non-affected muscles. |
| P5. Marconi et al. 2011 | Design: RCT Subjects (n): 30; EG15, CG 15 Age: EG 63.6 ± 7.6, CG 66.3 ± 11 Stroke type: Chronic Hemiplegia, R/L (n): 17/13 Intervention: EG- FMV and PT, CG- PT | MMAV (Motor Mao Area and Volume) SICI (Short Interval Intracortical Inhibition) SICF (Short Interval Intracortical Facilitation) | EG: Significant reduction in FCR vol. map and increase in EDC. SICI increased in FCR and reduced in EDC. Changes persisted up to 2 weeks after vibration. CG: No significant changes |
| Article and No. | Design and Participant Characteristics | Outcome Measure | Results |
|----------------|----------------------------------------|-----------------|---------|
| P6. Conrad et al. 2011 | Design: Single group pre-post | EPS (End Point Stability) | Improved EPS |
| Age: 54 ± 9 | Muscle activity | The mean absolute distance between hand position and target location at the end of a trial was 3.6 ± 1.2 cm. Stroke survivors had more success at making medial/lateral than proximal/distal. |
| Stroke type: Chronic | GP (Grip Pressure) | Muscle activity | Decreased stability error: Se, Pre 0.133 ± 0.048, Se, Post 0.077 ± 0.025 GP: 39.1 ± 13.3, 33.5 ± 11.3, 32.6 ± 10.4 |
| Hemiplegia, R/L (n): 4/6 | Intervention: FMV | | |
| Subjects (n): 10 | | | |
| P7. Noma et al. 2012 | Design: RCT | MAS EMG (F-wave) | RG: No significant changes observed |
| Subjects (n): 36; RG – 12, StG – 12, EG – 12 | | | StG: Decrease in F-wave amp. and F/M ratio immediately after vibration, but not 30 min later. |
| Age: RG 61 (27–83), StG 61.5 (41–83), EG 57.5 (38–83) | | | EG: Significant improvements in F-wave & MAS scores immediately after vibration which also remained 30 min later. |
| Stroke type: Acute | Hemiplegia, R/L (n): 16/20 | | |
| Intervention: RG (Rest Group) – no FMV, StG (Stretch Group)–FMV, EG – sham FMV | | | |
| P8. Caliandro et al. 2012 | Design: RCT | WMFT FAS (Wolf Motor Function Test Functional Ability Scale) | EG: number of patients with more than 0.37 points increase in WMFT FAS post-intervention increased |
| Subjects (n): 49; EG 28, CG 21 | MAS (Modified Ashworth Scale) | CC: No improvement in WMFT FAS No significant changes in MAS & VAS in CG or EG after 1 month of the intervention | |
| Age: EG 57.42 ± 12.79, CG 61.85 ± 15.74 | VAS (Visual Analog Scale) | | |
| Stroke type: Chronic | Hemiplegia, R/L (n): 23/26 | | |
| Intervention: EG- PT and FMV, CG- PT and sham | | | |
| P9. Lee et al. 2013 | Design: RCT | PS (Postural Sway) | PS: Greater improvements in distance with eyes-open (−11.91 vs. −11.10) and eyes-closed (−20.67 vs. −20.85) and velocity with eyes-open (−0.40 vs. −0.42) and eyes-closed (−0.69 vs. −0.71) in EG than CG. |
| Subjects (n): 31; EG 16, CG 15 | Gait | Gait: Greater improvement in gait speed (15.06 vs. 2.85), cadence (8.46 vs. 1.55), step length (7.90 vs. 3.64), and single limb support time (0.12 vs. 0.07) in EG than CG. | |
| Age: SG 53.31 ± 8.37, CG 55.73 ± 8.27 | | | |
| Stroke type: Chronic | Hemiplegia, R/L (n): 16/15 | | |
| Intervention: EG- PT, FES +FMV, CG- PT, FES+sham | | | |
| P10. Tavernese et al. 2013 | Design: RCT | Br-stage mRS (modified Rankin Scale) | Normalized jerk significantly decreased in the EG, but not in the CG. |
| Subjects (n): 44; EG 24, CG 20 | KE (Kinematic Evaluation) | Linear velocity significantly increased in the EG, but not in the CG. | |
| Age: EG 58.9 ± 14.7, CG 58.3 ± 12.4 | FMS (Fugl-Meyer Scale) | Angular velocity at shoulder significantly improved in EG, but not in CG. | |
| Stroke type: Chronic | MAS (Modified Ashworth Scale) | The movement duration significantly decreased in EG, but not in CG. | |
| Hemiplegia, R/L (n): 14/30 | Intervention: EG- PT and FMV, CG- PT | The distance to target significantly decreased in the EG, but not in CG. | |
Table 1. Cont.

| Article and No. | Design and Participant Characteristics | Outcome Measure | Results |
|-----------------|---------------------------------------|-----------------|---------|
| P11. Casale et al. 2014 | Design: RCT  
Subjects (n): 30; EG 15, CG 15  
Age: EG 64.7 ± 5.4, CG 65.1 ± 5.8  
Stroke type: NR  
Hemiplegia, R/L (n): 26/4  
Intervention: EG- PT and FMV, CG- PT and sham | MAS  
Robot sided motor task changes | EG: MAS significantly improved at T1 and T2 with respect to T0  
CG: the improvement reached statistical significance only at T2  
Similar results were observed for time to complete the tasks. |
| P12. Paolini et al. 2014 | Design: RCT  
Subjects (n): 22; EG 12, CG 10  
Age: EG 59.5 ± 13.3, CG 62.5 ± 9.5  
Stroke type: Chronic  
Hemiplegia, R/L (n): 8/14  
Intervention: EG- Exercise and FMV, CG- Exercise | MOT (Muscle Onset Time)  
CCI (Co-Contraction Index)  
MR (Modulation Ratio)  
%MVC (%Maximal Voluntary Contraction) | Significant differences between pre- and post-in the EG as regards the PD and ECR muscle onset times. No differences in CG.  
PD muscle onset time significantly closer to zero in the EG than in the CG.  
Patients in the EG had significantly lower CCI for the pairs BB/TB, PD/BB, and AD/BB.  
No differences in the CCI in the CG, except for Anterior and Posterior Deltoid.  
Post-CCI significantly lower in the EG for PD/BB and Anterior Deltoid/Biceps Brachii.  
Significantly better modulated AD and BB in EG.  
No differences in the CG.  
Post EG modulated the AD and BB significantly better than CG.  
BB %MCV value significantly lower in EG. |
| P13. Costantino et al. 2014 | Design: Single group pre-post  
Subjects (n): 16  
Age: 61.6 ± 15.5  
Stroke type: Chronic  
Hemiplegia, R/L (n): 15/1  
Intervention: FMV | GS (Grip Strength)  
MAS (Modified Ashworth Scale)  
Quick-DASH (The Disabilities of the Arm, Shoulder and Hand Score)  
FIM (Functional Independence Measure)  
FMS (Fugl-Meyer Scale)  
VNRS (Verbal Numerical Rating Scale)  
JTHFT (Jenssen-Taylor Hand Function Test) | GS in the paretic hand improved SP2  
14.75 ± 8.39, 18.31 ± 9.38; SP3 16.50 ± 9.86, 19.50 ± 11.00  
MAS: shoulder (1.44 ± 1.21, 1.00 ± 0.97), elbow (1.88 ± 1.15, 1.38 ± 1.09), wrist (1.63 ± 1.31, 1.00 ± 1.03)  
QuickDASH: 39.90 ± 16.01, 26.98 ± 17.13  
FIM: 80.50 ± 1533, 82.75 ± 14.69  
FMS: 85.00 ± 18.50, 96.75 ± 16.93  
VNRS: 2.88 ± 3.01, 1.31 ± 1.30  
JTHFT: 190.60 ± 125.63, 159.67 ± 117.16 |
| P14. Costantino et al. 2016 | Design: RCT  
Subjects (n): 32; EG 17, CG 15  
Age: EG 62.59 ± 15.39, CG 60.47 ± 16.0  
Stroke type: Chronic  
Hemiplegia, R/L (n): 9/23  
Intervention: EG- FMV, CG- sham FMV | GS (Grip Strength)  
MAS (Modified Ashworth Scale)  
Quick-DASH (The Disabilities of the Arm, Shoulder and Hand Score)  
FIM (Functional Independence Measure)  
FMS (Fugl-Meyer Scale)  
VNRS (Verbal Numerical Rating Scale)  
JTHFT (Jenssen-Taylor Hand Function Test) | GS in the paretic hand improved in EG (SP 2: 13.88 ± 8.88, 17.24 ± 10.11; SP3: 15.71 ± 10.09, 18.53 ± 11.37); in CG, a slight difference (SP2 unchanged at 17.33 ± 11.79; SP3 18.07 ± 11.25, 18.00 ± 11.26)  
MAS: shoulder (EG 1.59 ± 1.33, 1.12 ± 1.05; CG unchanged at 1.73 ± 1.28), elbow (EG: 2.00 ± 1.22, 1.47 ± 1.12; CG: 1.93 ± 1.22, 1.87 ± 1.19), wrist (EG: 1.76 ± 1.39, 1.18 ± 1.24; CG: 1.67 ± 1.35, 1.60 ± 1.30).  
QuickDASH: EG 41.17 ± 16.35, 39.01 ± 18.56, CG 40.55 ± 25.49, 39.74 ± 24.69  
FIM: EG 79.24 ± 15.83, 81.35 ± 15.35, CG 83.27 ± 10.96, 83.53 ± 11.06  
FMS: EG 82.82 ± 20.04, 94.24 ± 19.40 CG 83.33 ± 17.81, 84.27 ± 17.25  
VNRS: EG 2.88 ± 2.91, 1.24 ± 1.30 CG 2.13 ± 2.72, 1.80 ± 2.60  
JTHFT: EG 168.18 ± 133.48, 140.88 ± 121.74 CG 223.20 ± 163.89, 206.07 ± 153.53 |
Table 1. Cont.

| Article and No. | Design and Participant Characteristics | Outcome Measure | Results |
|----------------|----------------------------------------|-----------------|---------|
| P15. Go Eun-Ji et al. 2016 | Design: SSD Subjects (n): 3 Age: 58.3 Stroke type: Chronic Hemiplegia, R/L (n): 2/1 Intervention: FMV | BBT (Box and Block Test) 10-s Test FMS | Significant improvement in BBT and 10-s test. BBT: Participant 1 non-affected: 62.0 to 67.7; affected: 39.0 to 47.3 Participant 2 non-affected: 55.8 to 64.4; affected: 26.3 to 34.1 Participant 3 non-affected 33.3 to 40.0; affected 18.3 to 28.6 10-s test: Participant 1 FIMT 3.0 to 4.2, HPST 11.3 to 14.3, FTT 25.0 to 32.2 Participant 2 FIMT 2.0 to 3.4, HPST 7.0 to 10.6, FTT 26.3 to 34.1 Participant 3 FIMT 2.0 to 2.2, HPST 9.3 to 10.4, FTT 20.3 to 27.5 |
| P16. Bonan et al. 2017 | Design: Two group pre-post Subjects (n): 80; EG 40, CG 40 Age: EG 54.7 ± 10.5, CG 54.7 ± 10.5 Stroke type: Acute Hemiplegia, R/L (n): 21/19 Intervention: EG- FMV, CG- FMV | %BW Shift (% Body Weight Shift) | The evaluation was repeated 4-to-6 weeks (session 2) after the first test (session 1). Session 1: %shift1 for left HP patients (1.5% (5.3)) significantly lower than healthy subjects (4.8% (4.1)) and the right HP patients (4.9% (3.6)). Session 2: No significant difference between the 3 groups for %shift2. |
| P17. Calabro et al. 2017 | Design: RCT Subjects (n): 20; EG 10, CG 10 Age: EG 66 ± 5, CG 67 ± 4 Stroke type: Chronic Hemiplegia, R/L (n): 20/0 Intervention: EG- FMV+Robot, CG- sham FMV+Robot | MAS (Modified Ashworth Scale) SICI (Short Interval Intracortical Inhibition) HMR (Hmax/Mmax Ratio) FMS (Fugl-Meyer Scale) FIM (Functional Independence Measure) HRS-D (Hamilton Rating Scale for Depression) MEP (Motor-Evoked Potential) ICF (Intracortical Facilitation) | EG: greater reduction in the MAS and HMR and a more evident increase of SICI was observed up to 4 weeks after the end of the treatment, compared with CG. A significant correlation was found between the degree of MAS reduction and SICI increase in the agonist spastic muscles. |
| P18. Celletti et al. 2017 | Design: RCT Subjects (n): 18; G1-3 6 each Age: G1 43 (38–63), G2 43 (30–57), G3 62.5 (46–69) Stroke type: Chronic Hemiplegia, R/L (n): 9/9 Intervention: G1- FMV+RMP, G2- FMV+CP, G3- CP | WMFT (Wolf Motor Function Test) MAS (Modified Ashworth Scale) VAS (Visual Analog Scale) MI (Motricity Index) | Group 1: Increased WMFT (20, 48) and MI (39.5, 68.5), reduced VAS (5, 1.75) and MAS (2, 1.1). Group 2: Increased WMFT (24, 36) and MI (37.43), reduced VAS (5.75, 4) and MAS (2.6, 2.2). Group 3: Only reduced MAS. |
| P19. Jung Sang-Mi et al. 2017 | Design: Single group pre-post Subjects (n): 10 Age: 62.6 ± 8.6 Stroke type: Chronic Hemiplegia, R/L (n): 5/5 Intervention: FMV | GS (Grip Strength) BBT (Box and Block Test) WMT (Weinstein Monofilament Test) | Significant improvement in GS and BBT. All improvements retained after 2 weeks. GS: 11.4 ± 5.4, 13.4 ± 6.9, 12.6 ± 6.3 BBT: 13.3 ± 8.2, 17.1 ± 8.5, 15.1 ± 8.3 |
Table 1. Cont.

| Article and No. | Design and Participant Characteristics | Outcome Measure | Results |
|-----------------|---------------------------------------|-----------------|---------|
| **P20. Choi et al. 2017** | Design: RCT  
Subjects (n): 10; EG 5, CG 5  
Age: EG 62 ± 9, CG 59 ± 10.1  
Stroke type: Chronic Hemiplegia, R/L (n): 5/5  
Intervention: EG FMV, CG PT | BBT (Box and Block Test)  
GS (Grip Strength)  
WMT (Weinstein Monofilament Test) | BBT scores:  
EG: 18.6 ± 9.3, 22.2 ± 9.2; CG 20.4 ± 9.3, 21.8 ± 9.0  
Significant changes in BBT in EG and CG, no significant differences between EG and CG.  
GS and WMT scores did not improve significantly. |
| **P21. Toscano et al. 2019** | Design: RCT  
Subjects (n): 22; EG 10, CG 12  
Age: EG 64.7 ± 17.2, CG 69.5 ± 7.3  
Stroke type: Acute Hemiplegia, R/L (n): 10/12  
Intervention: EG FMV, CG sham FMV | NIHSS (National Institutes of Health Stroke Scale)  
FMS (Fugl-Meyer Scale)  
MI (Motricity Index)  
MAS (Modified Ashworth Scale) | EG patients showed a better clinical improvement in terms of stroke severity assessed by NIHSS, FMS, and MI than did CG patients. |
| **P22. Annino et al. 2019** | Design: RCT  
Subjects (n): 37; EG 19, CG 18  
Age: EG 67.8 ± 8.3, CG 69.4 ± 10.4  
Stroke type: Chronic Hemiplegia, R/L (n): 19/18  
Intervention: EG- FMV and PT, CG- PT | BI (Barthel Index)  
Goniometry  
MAS (Modified Ashworth Scale)  
MMT (Manual Muscle Testing) | EG: BI scores: 71.9 ± 22.9, 76.8 ± 21.7  
Goniometry: 115 ± 9.5, 116.2 ± 9.5  
MAS: 1.7 ± 0.7, 1.1 ± 0.8  
MMT flexor/extensor: 4 ± 0.8/4 ± 0.6, 4.2 ± 0.7/4.2 ± 0.7  
CG: BI scores: 78.6 ± 20.3, 81.0 ± 19.9  
Goniometry: 116.9 ± 9.7, 118.6 ± 9.1  
MAS: Not statistically improved  
MFT flexor/extensor: 3.7 ± 0.9/3.7 ± 0.8, 4 ± 0.8/3.8 ± 0.7 |

Table 2. Vibration devices, parameters, and protocols used in the included articles.

| Article | Device | FR (Hz) | A (mm) | Vibration Protocol |
|---------|--------|---------|--------|-------------------|
| **P1. Kawahira et al. 2004** | Custom Device | 83 | NR | Anterior tibial and gluteus medius  
1 single session for 14 s |
| **P2. Noma et al. 2009** | Thrive MD-01 | 91–108 | 1 | Palm flexor tendon and biceps brachii  
1 single session for 5 min |
| **P3. Paolini et al. 2010** | Horus | 120 | 0.01 | Peroneus longus and tibialis anterior  
4 weeks (30 min/day, 3 day/week) |
| **P4. Liepert et al. 2010** | Custom Device | 60 | NR | Forearm extensor muscles  
1 single session for 5 min |
| **P5. Marconi et al. 2011** | CROSYSTEM, NEMOCO | 100 | 0.2–0.5 | Flexor carpi radialis, biceps brachii  
3 consecutive days (30 min/day) |
| **P6. Conrad et al. 2011** | Custom Device | 70 | NR | Forearm flexor tendons  
1 single session with 40 trials (5 s/trial) |
| **P7. Noma et al. 2012** | Thrive MD-01 | 91–108 | 1 | Palmar flexor tendon, biceps brachii  
1 single session for 5 min |
| **P8. Caliandro et al. 2012** | CROSYSTEM, NEMOCO | 100 | 0.2–0.5 | Pectoralis minor, biceps brachii and flexor carpi  
3 consecutive days (30 min/day) |
| **P9. Lee et al. 2013** | NR | 90 | 0.015 | Achilles tendon, tibialis anterior  
6 weeks (30 min/day, 3 day/week) |
| **P10. Tavernese et al. 2013** | Horus | 120 | 0.01 | Biceps brachii and flexor carpi ulnaris  
2 weeks (30 min/day, 5 day/week) |
Table 2. Cont.

| Article                        | Device          | FR (Hz) | A (mm) | Vibration Protocol                                                                 |
|-------------------------------|-----------------|---------|--------|------------------------------------------------------------------------------------|
| P11. Casale et al. 2014       | VIBRA           | 100     | 2      | Triceps brachii 2 weeks (30 min/day, 5 day/week)                                    |
| P12. Paolini et al. 2014      | Horus           | 120     | 0.01   | Biceps brachii, flexor carpi ulnaris 2 weeks (30 min/day, 5 day/week)             |
| P13. Constantino et al. 2014 | ViSS Device     | 300     | 2      | Extensor carpi radialis longus, carpi radialis brevis, triceps brachii 4 weeks (30 min/day, 3 day/week) |
| P14. Costantino et al. 2016   | ViSS Device     | 300     | 2      | Carpi radialis longus, carpi radialis brevis, triceps brachii 4 weeks (30 min/day, 3 day/week) |
| P15. Go Eun-Ji et al. 2016    | Toothbrush      | 127     | NR     | Hand intrinsic/extrinsic muscles 6 weeks (30 min/day, 2 day/week)                  |
| P16. Bonan et al. 2017        | TechnoConcept VB115 | 90      | 0.4    | Non-paretic gluteus medius 1 session 35 s FMV after 15 s rest, repeatedly          |
| P17. Calabro et al. 2017      | VIBRA           | 80      | 0.3 ± 0.1 | Triceps brachii, supraspinatus, deltoid 8 weeks (1 h/day, 5 day/week)         |
| P18. Celletti 2017            | NR              | 100     | 0.2-0.5 | Pectoralis minor, biceps brachii, and flexor carpi 6 weeks (30 min/day, 3 consecutive day/week) |
| P19. Jung Sang-Mi 2017        | THRIVE MD-01    | 91–108  | 1      | Biceps brachii and flexor carpi radialis 2 weeks (30 min/day, 3 day/week)        |
| P20. Choi et al. 2017         | THRIVE MD-01    | 91      | 1      | Biceps brachii and flexor carpi radialis 4 weeks (30 min/day, 3 day/week)        |
| P21. Toscano et al. 2019      | CROSYSTEM, NEMOCO | 100   | 0.2-0.5 | Rectus femoris, biceps brachii, and flexor carpi radialis 3 consecutive days (30 min/day) |
| P22. Annino et al. 2019       | NR              | 30      | 2      | Triceps brachii 8 weeks (30 min/day, 3 day/week)                                   |

A: amplitude; FR: frequency; NR: not reported.

3.2. Participant Characteristics

A total of 541 patients with post-stroke, with 287 right hemiplegic and 254 left hemiplegics, were included. The mean age for all participants with stroke was 60 years. Four studies included acute stroke patients [44,45,49,62]; 17 studies investigated chronic stroke (>12 months) [41–43,46–48,50,51,53–61]; and one did not provide sufficient information about the stage of the stroke [52], as shown in Table 1.

3.3. Study Design

The seven quasi-experimental design studies and the single subject design study investigated only FMV [41,44–46,48,54,56,59]. Two studies investigated FMV versus sham FMV [55,62]. One study examined FMV versus physical therapy (PT) [60]. Six examined FMV plus PT versus PT [42,47,50–52,61]. One investigated FMV, FES and PT versus FES, and PT plus sham FMV [43]. One study examined FMV versus exercise [53]. One investigated FMV plus robotic rehabilitation versus sham FMV plus robotic rehabilitation [57]. One study examined FMV plus progressive modular rebalancing versus FMV plus PT versus PT only [58]. One studied FMV versus stretching and rest [49].

3.4. Vibration Parameters and Protocols

3.4.1. Vibration Device

Of the 22 articles, three did not report the vibration device used [43,58,61]. A total of seven devices were reported. Four studies used the Thrive MD-01 (Thrive Co., Ltd, Osaka, Japan) [45,49,59,60]. Three used the Horus (Akropolis, Rome, Italy) [42,51,53]. Three used the CROSYSTEM (NEMOCO, srl, Italy) [47,50,62]. Three studies used customized devices [41,46,48]. Two used the ViSS device (Vissman, Rome,
Two studies used VIBRA (Circle, Ferrara, Italy) [52,57]. The remaining studies used
Powered Toothbrush (manufacturer, city and country not specified) [56] and TechnoConcept VB115
(TechnoConcept, Manosque, France) [44], respectively. All studies were conducted in clinical settings.

3.4.2. Vibration Frequency and Amplitude

The frequencies and the amplitudes used in the included studies are represented graphically in
Figure 2. The most frequently used combination was 100 Hz and 0.2–0.5 mm [47,50,58,62], followed by
120 Hz and 0.01 mm [42,51,53] and 99.5 Hz and 1 mm [45,49,59]. The FMV frequency ranged from
30 Hz to 300 Hz and the amplitude ranged from 0.01 mm to 2 mm.

![Figure 2. Vibration frequencies and amplitudes used in the included studies. The results were presented as (amplitude, frequency), [article number(s)]. NR means not reported in the article. Articles did not report amplitude were plotted as 0 mm.](image)

3.4.3. Vibration Protocols

In terms of the muscles where the vibration was applied, 20 different muscles were targeted,
with five muscles for lower extremities and 15 muscles for upper extremities (Figure 3). Biceps brachii
was targeted the most, followed by triceps brachii and flexor carpi radialis.

![Figure 3. Muscles targeted for the FMV and studies using each muscle.](image)
The frequency of treatments ranged from a single session [41,44–48,49] to two [56], three [42,43,47,50,54,55,58–62], or five times per week [51–53,57]. The duration of the treatment protocol was one day [41,44–46,48,49], three days [47,50,62], two weeks [51–53,59], four weeks [42,54,55,60], six weeks [43,56,58], or eight weeks [57,61]. The vibration durations were 14 to 20 s [41,48], 5 min [45,46,49], 30 min [42,43,47,50–56,58–62], or 60 min [37]. One study did not specify the duration of the vibration. Instead, the participant received repeated FMV for 35 s after a 15 s rest until they felt better [44].

Thirty-seven different outcome measures were used across the 22 studies. The most common outcome measure was assessment of the spasticity via the modified Ashworth scale, which was used in 11 studies, followed by grip strength assessed in five studies, and Fugl-Meyer scale and box and block test evaluated in four studies each. Figure 4 shows all outcome measures and how commonly they were used across studies.

Figure 4. Outcome measures used and number of studies using each outcome measure.

4. Discussion

To our knowledge, this is the first review aimed to investigate FMV devices, parameters, protocols, and outcome measures in post-stroke rehabilitation. The only other review of FMV for stroke rehabilitation was a systematic review focused on the effectiveness of FMV on hemiplegic upper extremity spasticity in individuals with stroke [28]. Our review agreed with the findings that FMV therapy may reduce spasticity in both upper and lower extremities and improve function in individuals with stroke [28,29]. The positive effect of FMV in inhibiting hemiplegic upper and lower extremity spasticity in patients with strokes was confirmed with other reviews [25,28,29].

Included studies were primarily quasi-experimental design and RCTs. Most studies did not justify the choice of target muscles for vibration or provide the rationale behind the vibration protocols. Blinding of participants and therapists was poor, although the assignment of control and experimental groups was randomized. There was overall a lack of follow-up post FMV intervention to determine how long the improvements would last. Marconi et al. (2011) and Jung Sang-mi et al. (2017) examined the effects of FMV therapy after two weeks of intervention and reported that, even though the changes on the main outcome measures were less than observed immediately post interventions, patients were still better than baseline [47,59]. This finding indicates that the benefit of FMV therapy might last for two weeks. Caliandro et al. (2012) and Calarbo et al. (2017) checked the participants one month after the FMV therapy, and there were no significant differences on the outcome measures [50,57]. In addition, the included studies did not compare FMV therapy with other interventions, except for...
traditional physical therapy (PT). There was agreement with our review and others that a wide variety of FMV devices with different vibration frequencies, amplitude, targeted muscles, vibration protocol, and outcome measures were used [25,28,29].

Seven different vibration devices were used in the 19 studies that reported the vibration devices. The technical details of those devices were ambitiously described, but their availability for clinical and home use were not clear. In the 22 included studies, participants visited the clinics for the vibration interventions, which could lead to poor compliance for sustainable usage of the FMV therapy.

Recently, newer wearable FMV technologies were developed, including the Equistasi® (Equistasi S.R.L. Via C.Porta, 16 20064 Gorgonzola, Italy), VibraCool® (Pain Care Labs, 195 Arizona Ave LW08, Atlanta, GA 30307, USA), and Myovolt (Myovolt Limited 146a Litchfield Street, Christchurch 8011, New Zealand). Equistasi® uses nanotechnology fibers to deliver frequency as high as 9000 Hz with very low amplitude less than 0.002 mm. It has been used to treat Parkinson’s disease [63–65], multiple sclerosis [66], and ataxia [67,68]. However, due to the much higher frequency and the lower amplitude, the mechanism of Equistasi® might not be the same as that of the FMV discussed in this study. In addition, Equistasi® has not been used for patients with stroke to our knowledge. VibraCool® uses proprietary high-speed vibration frequencies and intense cold for pain relief and to treat muscle tension and myofascial trigger points. Research evidence on VibraCool® appears unavailable, and its technical specifications were not reported on their website. Myovolt combines therapeutic vibration together with a gentle warming effect to massage and relieve muscle soreness and stiffness. Studies conducted using Myovolt reported improvement in muscular power performance [69] and alleviation of muscle soreness in healthy adults [70] and improved muscle function in patients with peripheral artery disease [71]. All of these wearable FMV technologies showed promise but with limited application or evidence in stroke rehabilitation. Future studies are warranted to explore their benefits with individuals with stroke.

More than half of the studies used vibration frequencies from 85 to 120 Hz and vibration amplitudes of 0.01–2 mm. A reduction in spasticity was observed with various frequency ranges. Due to the variations in amplitude and treatment frequency and duration, and contradictory to what is stated in the recent review [28], we speculate that vibration frequency cannot be disregarded as a discriminative factor in FMV intervention. We believe that studies with rigorous design controlling for vibration amplitude and treatment protocol will be needed to investigate the impact of vibration frequency in FMV intervention. The vibration amplitude for stroke rehabilitation ranging from 0.01 mm to 2 mm was considered comparable to the vibration amplitude ranging from 0.005 mm to 10 mm in studies using FMV intervention for patients with spinal cord injury, multiple sclerosis, and other movement disorders [25,29,72]. About one third of articles on FMV did not report the amplitude delivered. The improvements observed in the outcome measurement scores were better in studies using FMV with amplitudes greater than or equal to 1 mm and frequencies in the range of 91–108 Hz or greater [45,49,52,54,55,59–61], unless FMV was paired with other forms of intervention such as robotic assistive device [57] or progressive modular re-balancing (RMP) [58]. FMV alone with lower frequencies of less than 90 Hz and lower amplitudes of less than 1 mm seemed to have a lesser change in the outcome measures. Given that frequency range 75–120 Hz was particularly effective on the central nervous network underlying motor control [73], and amplitude of 1–2 mm was sufficient to drive Ia spindle afferents while remaining safe for the tonic vibration reflex [74] and avoiding muscle fiber injury [75], these frequency and amplitude combinations could be recommended for future studies. The duration of intervention did not seem to have much effect on the total improvement, although the change scores were slightly greater in studies with longer durations of intervention, which could be because of the long-lasting effects on cortical excitability. In addition to exploring the impact of vibration frequency, it is necessary to conduct basic science research on how muscle spindles, neurons, and human tissues respond to the different amplitudes delivered by the vibration motor to understand the individual and the combined impact of the vibration parameters as well as to optimize vibration parameters for individual patients.
A single session of vibration while walking for 14 s was reported to improve the walking speed of patients with stroke [41]. Further, a single session lasting 5 min inhibited spasticity and improved muscle performance, as measured by EMG [45,46,49]. Although these studies were of high quality with larger sample sizes, the results were insufficient for generalization. These findings may implicate the acute effect of FMV in stroke rehabilitation, as also observed in professional athletes [69]. With more frequent and longer duration (5 min FMV + 30 min PT × 3/week × 8 week) and more FMV (30 min FMV × 3/week × 6 week), small to moderate effect sizes (0.11–0.52) were observed in studies with relatively high methodological quality [55,61]. Other studies with less FMV (30 min FMV + 60 min PT × 5/week × 2 week) also reported significant reduction in spasticity in the experimental group compared with the control group [51–53,59]. More FMV might lead to better outcomes, but there is a lack of evidence regarding the best vibration dosage and duration. Thus, future studies to investigate and standardize the protocol for FMV interventions are warranted. The overall lack of follow-up after the FMV interventions made it difficult to determine the long-term effects, even though some studies stated that FMV intervention effects could last as long as two weeks [47] and even four months after the intervention in elder adults [76].

A variety of muscles were targeted for FMV therapy. For upper extremity rehabilitation, triceps brachii and biceps brachii were targeted the most. Shorter fascicle lengths have been reported for the brachialis muscle on the affected side, as shown by ultrasound [77]. The flexor carpi radialis was also frequently targeted because shortening of wrist flexor muscles is associated with poor recovery after stroke [78]. For the lower extremity rehabilitation application of FMV, three out of the five studies targeted the tibialis anterior muscle. This focus could be due to the importance of tibialis anterior in gait and that the affected lower limb exhibited significantly longer delays in initiation and termination of tibialis anterior contraction relative to the unaffected limb in individuals with stroke [79,80]. Overall, there was a lack of justification for the choice of target muscles and discussions on the clinical rationales and applications of the findings based on the muscles that received vibration. Six studies reported electrophysiology [42,45,47–49,53]. There was no clear mechanism through which FMV acts on the sensorimotor system. All six studies hypothesized the mechanism of increasing Ia afferent fiber discharges because of the activation of muscle spindles via FMV. The modulation of Ia inputs altered the excitability of the corticospinal pathway as well as the activation of cortical motor regions. However, excitability remained unchanged in other cortical motor representations, indicating that the increased neuronal excitability was specific to the vibrated muscle’s movement representation [42,53]. For FMV applied to low extremity muscles, such as quadriceps during the stance phase of walking, group Ia afferent discharges also contributed to the triggering of locomotor phase transitions [42]. It was also noted that FMV affects not only the contralateral but also the ipsilateral hemisphere, thereby modulating the relationship between the two hemispheres [42]. For FMV applied to upper extremity muscles, it was hypothesized that FMV applied to the forearm improved regulation of reflex excitability and improved cortical control of the movement [48]. In addition, the effects of FMV might depend on the inhibitory/ excitatory state within the motor system reflecting the site of lesion for stroke patients [47]. The underlying mechanism of motor and function recovery due to vibration at different muscles could be more complex than simply the activation of Ia afferents. Measurements to detect activation of sensorimotor cortex network, nitric oxide production, and blood flow could be included in the future studies to better understand how vibration at different muscles impact the outcomes.

Based on the International Classification of Functioning, Disability, and Health [81], 22 of the outcome measures in the included studies are considered measures of body function and structure (BBT (Box and Block Test), Br-Stage (Brunnstorm stage), CCI (Co-Contraction Index), EMG (Electromyograph), Goniometry, GP/GS (Grip Pressure/Grip Strength), HMR (Hmax/Mmax Ratio), ICF (Intracortical Fascilitation), MAS (Modified Ashworth Scale), MEP (Motor-Evoked Potential), MI (Motricity Index), MMAV (Motor Map Area and Volume), MMT (Manual Muscle Test), MOT (Muscle Onset Time), MR (Modulation Ratio), PS (Postural Sway), SICF (Short Interval Intracortical Facilitation),
SICI (Short Interval Intracortical Inhibition), STEF (Simple Test for Evaluating hand Function), WMT (Weinstein Monofilament Test), %BW shift (% Body Weight Shift), %MVC (% Maximal Voluntary Contraction)); nine measured activity (BI (Barthel Index), EPS (End Point Stability), FAS (Functional Ability Scale), FIM (Functional Independence Measure), JYHFT (Jebsen-Taylor Hand Function Test), KE (Kinematic Evaluation), mRS (modified Rankin Scale), QuickDash (The Disabilities of the Arm, Shoulder and Hand Score), WMFT (Wolf Motor Function Test)); three assessed the health condition (CSP (Cortical Silent Period), FMS (Fugl-Meyer Scale), NIHSS (National Institutes of Health Stroke Scale)); and three measured personal factors (FIM (Functional Independence Measure), VAS (Visual Analog Scale), VNRS (Verbal Numerical Rating Scale)). Thus, the focus of the included studies was on effect of FMV on health and function, with little or no focus on participation and quality of life. This could be partly due to the overall short durations of those studies, which could make investigating changes in participation and quality of life difficult. This finding could also be attributed to the infancy of FMV therapy for stroke rehabilitation and the lack of accessible and sustainable FMV devices for researchers, clinicians, and individuals with stroke.

This review was limited to articles published in English. Regarding the locations where the research was conducted, only one was conducted in the United States; one was in Germany; one in France; three in Japan; four in Korea; and twelve in Italy. This can lead to bias, as studies published in languages other than English were not included. In addition, it is known that significant results have greater likelihood of publication than do studies that do not have significant results. Effect sizes were not reported for most outcome measures because of the inconsistency of outcome measures and insufficient data. We did not conduct meta-analysis because the focus of this review was vibration technology and protocol, because of the heterogeneity of treatment protocols, dosages, and assessment, and because of the inability to contact the authors of many articles.

5. Conclusions

In conclusion, FMV may reduce spasticity and improve function in individuals with stroke when it is applied to the antagonist muscles. However, the effects of FMV on stroke rehabilitation are not fully understood. The accessibility and the sustainability of existing FMV technology, effectiveness of treatment protocol, and dosage remain unclear. Furthermore, the included studies did not report details on the vibration devices, with highly varied muscles vibrated, vibration frequency and amplitude, treatment protocol, and outcome measures. These variations make it difficult to recommend the clinical application of FMV therapy. These findings illustrate the need for more research to understand the mechanisms of FMV in stroke rehabilitation, and the impact of characteristics of the vibration device on outcome measures. Further high-quality studies with large sample sizes are warranted.

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Abbreviations

Acronyms used in “Study Design and Participant” column, “Outcome Measures” column, and “Results” column:

| Acronym | Description |
|---------|-------------|
| AD/PD   | Anterior/Posterior Deltoid |
| AROM    | Active Range of Motion |
| BB      | Biceps Brachii |
| BBT     | Box and Block Test |
| BI      | Barthel Index |
| Br-stage| Brunnstrom stage |
| BW      | Body Weight |
| CCI     | Co-Contraction Index |
| CG      | Control Group |
| CP      | Conventional Physiotherapy |
| CSP     | Cortical Silent Period |
| ECR     | Extensor Carpi Radialis |
| EDC     | Extensor Digitorum Communis |
| EG      | Experimental Group |
| EMG     | Electromyograph |
| EPS     | End Point Stability |
| FAS     | Functional Ability Scale |
| FCR     | Flexor Carpi Radialis |
| FES     | Functional Electrical Stimulation |
| FMV     | Focal Muscle Vibration |
| FIM     | Functional Independence Measure |
| FMS     | Fugl-Meyer Scale |
| G1/G2/G3| Group 1/2/3 |
| GP      | Grip Pressure |
| GS      | Grip Strength |
| HRS-D   | Hamilton Rating Scale for Depression |
| HMR     | Hmax/Mmax Ratio |
| ICF     | Intracortical Facilitation |
| JTHFT   | Jebsen-Taylor Hand Function Test |
| KE      | Kinematic Evaluation |
| MAS     | Modified Ashworth Scale |
| MI      | Motricity Index |
| MMAV    | Motor Map Area and Volume |
| MR      | Modulation Ratio |
| MOT     | Muscle Onset Time |
| mRS     | modified Rankin Scale |
| MVC     | Maximal Voluntary Contraction |
| PS      | Postural Sway |
| PT      | Physical Therapy |
| RCT     | Randomized Control Trial |
| RG      | Rest Group |
| RMP     | Progressive Modular Re-balancing |
| SICF    | Short Interval Intracortical Facilitation |
| SICI    | Short Interval Intracortical Inhibition |
| SSD     | Single Subject Design |
| STEF    | Simple Test for Evaluating hand Function |
| SIG     | Stretch Group |
| TB      | Triceps Brachii |
| VAS     | Visual Analog Scale |
| VNRS    | Verbal Numerical Rating Scale |
| WMFT    | Wolf Motor Function Test |
| WMT     | Weinstein Monofilament Test |
References

1. Katan, M.; Luft, A. Global burden of stroke. In *Seminars in Neurology*; Georg Thieme Verlag: Stuttgart, Germany, 2018.

2. Bolognini, N.; Russo, C.; Edwards, D.J. The sensory side of post-stroke motor rehabilitation. *Restor. Neurol. Neurosci.* 2016, 34, 571–586. [CrossRef] [PubMed]

3. Hughes, C.M.L.; Tommasino, P.; Buchhota, A.; Camplolo, D. Upper extremity proprioception in healthy aging and stroke populations, and the effects of therapist-and robot-based rehabilitation therapies on proprioceptive function. *Front. Hum. Neurosci.* 2015, 9, 120. [CrossRef] [PubMed]

4. Hendricks, H.T.; van Limbeek, J.; Geurts, A.C.; Zwarts, M.J. Motor recovery after stroke: A systematic review of the literature. *Arch. Phys. Med. Rehabil.* 2002, 83, 1629–1637. [CrossRef] [PubMed]

5. Adeoye, O.; Nyström, K.V.; Yavagal, D.R.; Luciano, J.; Nogueira, R.G.; Zorowitz, R.D.; Khalessi, A.A.; Bushnell, C.; Barsan, W.G.; Panagos, P.; et al. Recommendations for the establishment of stroke systems of care: A 2019 update: A policy statement from the American Stroke Association. *Stroke* 2019, 50, e187–e210. [CrossRef] [PubMed]

6. Westwater-Wood, S.; Adams, N.; Kerry, R. The use of proprioceptive neuromuscular facilitation in physiotherapy practice. *Phys. Ther. Rev.* 2010, 15, 23–28. [CrossRef]

7. Oujamaa, L.; Relave, I.; Froger, J.; Mottet, D.; Pelissier, J.Y. Rehabilitation of arm function after stroke. Literature review. *Ann. Phys. Rehabil. Med.* 2009, 52, 269–293. [PubMed]

8. Hong, Z.; Sui, M.; Zhuang, Z.; Liu, H.; Zheng, X.; Cai, C.; Jin, D. Effectiveness of neuromuscular electrical stimulation on lower limbs of patients with hemiplegia after chronic stroke: A systematic review. *Arch. Phys. Med. Rehabil.* 2018, 99, 1011–1022. [CrossRef]

9. Quandt, F.; Hummel, F.C. The influence of functional electrical stimulation on hand motor recovery in stroke patients: A review. *Exp. Transl. Stroke Med.* 2014, 6, 1–7. [CrossRef]

10. Laufer, Y.; Elboim-Gabyzon, M. Does sensory transcutaneous electrical stimulation enhance motor recovery following a stroke? A systematic review. *Neurorehabil. Neural Repair* 2011, 25, 799–809. [CrossRef]

11. Mahmood, A.; Veluswamy, S.K.; Hombali, A.; Mullick, A.; Manikandan, N.; Solomon, J.M. Effect of transcutaneous electrical nerve stimulation on spasticity in adults with stroke: A systematic review and meta-analysis. *Arch. Phys. Med. Rehabil.* 2019, 100, 751–768. [CrossRef]

12. Stanton, R.; Ada, L.; Dean, C.M.; Preston, E. Biofeedback improves activities of the lower limb after stroke: A systematic review. *J. Physiother.* 2011, 57, 145–155. [CrossRef]

13. van Duijnhoven, H.J.; Heeren, A.; Peters, M.A.; Veerbeek, J.M.; Kwakkel, G.; Geurts, A.C.; Weerdesteyn, V. Effects of exercise therapy on balance capacity in chronic stroke: Systematic review and meta-analysis. *Stroke* 2016, 47, 2603–2610. [CrossRef] [PubMed]

14. Ammann, B.C.; Knols, R.H.; Baschung, P.; De Bie, R.A.; Bruin, E.D. Application of principles of exercise training in sub-acute and chronic stroke survivors: A systematic review. *BMC Neurol.* 2014, 14, 167. [CrossRef] [PubMed]

15. Latimer, C.P.; Keeling, J.; Lin, B.; Henderson, M.; Hale, L.A. The impact of bilateral therapy on upper limb function after chronic stroke: A systematic review. *Disabil. Rehabil.* 2010, 32, 1221–1231. [CrossRef] [PubMed]

16. Pérez-Cruzado, D.; Merchán-Baeza, J.A.; González-Sánchez, M.; Cuesta-Vargas, A.I. Systematic review of mirror therapy compared with conventional rehabilitation in upper extremity function in stroke survivors. *Aust. Occup. Ther. J.* 2017, 64, 91–112. [CrossRef]

17. Bertani, R.; Melegari, C.; Maria, C.; Bramanti, A.; Bramanti, P.; Calabrò, R.S. Effects of robot-assisted upper limb rehabilitation in stroke patients: A systematic review with meta-analysis. *Neurol. Sci.* 2017, 38, 1561–1569. [CrossRef]

18. Bruni, M.F.; Melegari, C.; De Cola, M.C.; Bramanti, A.; Bramanti, P.; Calabrò, R.S. What does best evidence tell us about robotic gait rehabilitation in stroke patients: A systematic review and meta-analysis. *J. Clin. Neurosci.* 2018, 48, 11–17. [CrossRef]

19. Iruthayarajah, J.; McIntyre, A.; Cotoi, A.; Macaluso, S.; Teasell, R. The use of virtual reality for balance among individuals with chronic stroke: A systematic review and meta-analysis. *Top. Stroke Rehabil.* 2017, 24, 68–79. [CrossRef]
20. Lee, S.H.; Park, Y.J.; Park, S.W. The effects of virtual reality training on function in chronic stroke patients: A systematic review and meta-analysis. BioMed Res. Int. 2019. [CrossRef]
21. Teasell, R.; Mehta, S.; Pereira, S.; McIntyre, A.; Janzen, S.; Allen, L.; Lobo, L.; Viana, R. Time to rethink long-term rehabilitation management of stroke patients. Top. Stroke Rehabil. 2012, 19, 457–462.
22. Teasell, R.W.; Fernandez, M.M.; McIntyre, A.; Mehta, S. Rethinking the continuum of stroke rehabilitation. Arch. Phys. Med. Rehabil. 2014, 95, 595–596. [CrossRef] [PubMed]
23. Weinstein, C.J.; Stein, J.; Arena, R.; Bates, B.; Cherney, L.R.; Cramer, S.C.; Deruyter, F.; Eng, J.J.; Fisher, B.; Harvey, R.L.; et al. Guidelines for adult stroke rehabilitation and recovery: A guideline for healthcare professionals from the American Heart Association/Association American Stroke Association. Stroke 2016, 47, e98–e169. [CrossRef] [PubMed]
24. Young, J.; Forster, A. Review of stroke rehabilitation. BMJ 2007, 334, 86–90. [CrossRef] [PubMed]
25. Yang, F. Application of Vibration Training in People with Common Neurological Disorders. In Manual of Vibration Exercise and Vibration Therapy; Springer International: Cham, Switzerland, 2020; pp. 343–353.
26. Schröder, J.; Truijen, S.; Van Criekinge, T.; Saeyes, W. Peripheral somatosensory stimulation and postural recovery after stroke—A systematic review. Top. Stroke Rehabil. 2018, 25, 312–320.
27. Celletti, C.; Suppa, A.; Bianchini, E.; Lakin, S.; Toscano, M.; La Torre, G.; Di Piero, V.; Camerota, F. Promoting post-stroke recovery through focal or whole body vibration: Criticisms and prospects from a narrative review. Neurol. Sci. 2020, 41, 11–24. [CrossRef]
28. Alashram, A.R.; Padua, E.; Romagnoli, C.; Annino, G. Effectiveness of focal muscle vibration on hemiplegic upper extremity spasticity in individuals with stroke: A systematic review. NeuroRehabilitation 2019, 45, 471–481. [CrossRef]
29. Murillo, N.; Valls-Sole, J.; Vidal, J.; Opisso, E.; Medina, J.; Kumru, H. Focal vibration in neurorehabilitation. Eur. J. Phys. Rehabil. Med. 2014, 50, 231–242.
30. Huang, M.; Pang, M.Y.C. Muscle activity and vibration transmissibility during whole-body vibration in chronic stroke. Scand. J. Med. Sci. Sports 2019, 29, 816–825. [CrossRef]
31. Steyvers, M.; Levin, O.; Van Baelen, M.; Swinnen, S.P. Corticospinal excitability changes following prolonged muscle tendon vibration. Neuroreport 2003, 14, 1901–1905. [CrossRef]
32. Yang, F.; Butler, A.J. Efficacy of controlled whole-body vibration training on improving fall risk factors in stroke survivors: A meta-analysis. Neurorehabilit. Neural Repair 2020, 34, 275–288. [CrossRef]
33. Park, Y.J.; Park, S.W.; Lee, H.S. Comparison of the Effectiveness of Whole Body Vibration in Stroke Patients: A Meta-Analysis. BioMed Res. Int. 2018, 2018, 5083634. [CrossRef] [PubMed]
34. Sañudo, B.; Tairas, R.; Furness, T.; Bernardo-Filho, M. Clinical Approaches of Whole-Body Vibration Exercises in Individuals with Stroke: A Narrative Revision. Rehabil. Res. Pract. 2018. [CrossRef]
35. Lee, A.; Kim, H.; Kim, J.; Choi, D.S.; Jung, J.H.; Lee, J.; Kim, Y.H. Modulating Effects of Whole Body Vibration on Cortical Activity and Gait Function in Chronic Stroke Patients. Brain Neurorehabilit. 2019, 13. [CrossRef]
36. Yang, X.; Wang, P.; Liu, C.; He, C.; Reinhardt, J.D. The effect of whole body vibration on balance, gait performance and mobility in people with stroke: A systematic review and meta-analysis. Clin. Rehabil. 2015, 29, 627–638. [CrossRef] [PubMed]
37. Lu, J.; Xu, G.; Wang, Y. Effects of whole body vibration training on people with chronic stroke: A systematic review and meta-analysis. Top. Stroke Rehabil. 2015, 22, 161–168. [CrossRef] [PubMed]
38. Liao, L.-R.; Huang, M.; Lam, F.M.; Pang, M.Y. Effects of whole-body vibration therapy on body functions and structures, activity, and participation poststroke: A systematic review. Phys. Ther. 2014, 94, 1232–1251. [CrossRef]
39. Pozo-Cruz, B.d.; Adua, J.C.; Parraca, J.A.; Pozo-Cruz, J.D.; Olivares, P.R.; Gusi, N. Using whole-body vibration training in patients affected with common neurological diseases: A systematic literature review. J. Altern. Complementary Med. 2012, 18, 29–41. [CrossRef]
40. Huang, M.; Liao, L.-R.; Pang, M.Y. Effects of whole body vibration on muscle spasticity for people with central nervous system disorders: A systematic review. Clin. Rehabil. 2017, 31, 23–33. [CrossRef]
41. Kawahira, K.; Higashihara, K.; Matsumoto, S.; Shimodozono, M.; Etoh, S.; Tanaka, N.; Sueyoshi, Y. New functional vibratory stimulation device for extremities in patients with stroke. Int. J. Rehabil. Res. 2004, 27, 335–337. [CrossRef]
42. Paoloni, M.; Mangone, M.; Scettì, P.; Procacciante, R.; Cometa, A.; Santilli, V. Segmental muscle vibration improves walking in chronic stroke patients with foot drop: A randomized controlled trial. Neuromodulation. Neural Repair 2010, 24, 254–262. [CrossRef]  
43. Lee, S.-W.; Cho, K.-H.; Lee, W.-H. Effect of vibration stimulus training programme on postural sway and gait in chronic stroke patients: A randomized controlled trial. Clin. Rehabil. 2013, 27, 921–931. [CrossRef] [PubMed]  
44. Bonan, I.; Butet, S.; Jamal, K.; Yelnik, A.; Ponche, S.T.; Leplaideur, S. Difference between individuals with left and right hemiparesis in the effect of gluteus medius vibration on body weight shifting. Neurophysiol. Clin. 2017, 47, 419–426. [CrossRef] [PubMed]  
45. Noma, T.; Matsumoto, S.; Etoh, S.; Shimodozono, M.; Kawahira, K. Anti-spastic effects of the direct application of vibratory stimuli to the spastic muscles of hemiplegic limbs in post-stroke patients. Brain Inj. 2009, 23, 623–631. [CrossRef] [PubMed]  
46. Liepert, J.; Binder, C. Vibration-induced effects in stroke patients with spastic hemiparesis—A pilot study. Restor. Neurol. Neurosci. 2010, 28, 729–735. [CrossRef]  
47. Marconi, B.; Filippi, G.M.; Koch, G.; Giacobbe, V.; Pecchioli, C.; Versace, V.; Camerota, F.; Saraceni, V.M.; Caltagirone, C. Long-term effects on cortical excitability and motor recovery induced by repeated muscle vibration in chronic stroke patients. Neurorehabil. Neural Repair 2011, 25, 48–60. [CrossRef]  
48. Conrad, O.M.; Scheidt, R.A.; Schmit, B.D. Effects of wrist tendon vibration on targeted upper-arm movements in poststroke hemiparesis. Neurorehabil. Neural Repair 2011, 25, 61–70. [CrossRef]  
49. Noma, T.; Matsumoto, S.; Shimodozono, M.; Etoh, S.; Kawahira, K. Anti-spastic effects of the direct application of vibratory stimuli to the spastic muscles of hemiplegic limbs in post-stroke patients: A proof-of-principle study. J. Rehabil. Med. 2012, 44, 325–330. [CrossRef]  
50. Caliandro, P.; Celletti, C.; Padua, L.; Minciotti, I.; Russo, G.; Granata, G.; La Torre, G.; Granieri, E.; Camerota, F. Focal muscle vibration in the treatment of upper limb spasticity: A pilot randomized controlled trial in patients with chronic stroke. Arch. Phys. Med. Rehabil. 2012, 93, 1656–1661. [CrossRef]  
51. Tavernese, E.; Paoloni, M.; Mangone, M.; Mandic, V.; Sale, P.; Franceschini, M.; Santilli, V. Segmental muscle vibration improves reaching movement in patients with chronic stroke. A randomized controlled trial. NeuroRehabilitation 2013, 32, 591–599. [CrossRef]  
52. Casale, R.; Damiani, C.; Maestri, R.; Fundarò, C.; Chimento, P.; Foti, C. Localized 100 Hz vibration improves function and reduces upper limb spasticity: A double-blind controlled study. Eur. J. Phys. Rehabil. Med. 2014, 50, 495–504.  
53. Paoloni, M.; Tavernese, E.; Fini, M.; Sale, P.; Franceschini, M.; Santilli, V.; Mangone, M. Segmental muscle vibration modifies muscle activation during reaching in chronic stroke: A pilot study. NeuroRehabilitation 2014, 35, 405–414. [CrossRef] [PubMed]  
54. Constantino, C.; Galuppo, L.; Romiti, D. Efficacy of mechano-acoustic vibration on strength, pain, and function in poststroke rehabilitation: A pilot study. Top. Stroke Rehabil. 2014, 21, 391–399. [CrossRef] [PubMed]  
55. Costantino, C.; Galuppo, L.; Romiti, D. Short-term effect of local muscle vibration treatment versus sham therapy on upper limb in chronic post-stroke patients: A randomized controlled trial. Eur. J. Phys. Rehabil. Med. 2017, 53, 32–40. [PubMed]  
56. Go, J.-E.; Lee, S.-H. Effect of sensorimotor stimulation on chronic stroke patients’ upper extremity function: A preliminary study. J. Phys. Ther. Sci. 2016, 28, 3350–3353. [CrossRef]  
57. Calabro, R.S.; Naro, A.; Russo, M.; Milardi, D.; Leo, A.; Filoni, S.; Trinchera, A.; Bramanti, P. Is two better than one? Muscle vibration plus robotic rehabilitation to improve upper limb spasticity and function: A pilot randomized controlled trial. PLoS ONE 2017, 12, e0189936. [CrossRef]  
58. Celletti, C.; Sinibaldi, E.; Pierelli, F.; Monari, G.; Camerota, F. Focal muscle vibration and progressive modular rebalancing with neurokinetic facilitations in post-stroke recovery of upper limb. Clin. Ther. 2017, 168, e33–e36.  
59. Jung, S.-M. The effects of vibratory stimulation employed to forearm and arm flexor muscles on upper limb function in patients with chronic stroke. J. Phys. Ther. Sci. 2017, 29, 1620–1622. [CrossRef]
60. Choi, W.-H. Effects of repeated vibratory stimulation of wrist and elbow flexors on hand dexterity, strength, and sensory function in patients with chronic stroke: A pilot study. *J. Phys. Ther. Sci.* 2017, 29, 605–608. [CrossRef]
61. Annino, G.; Alashram, A.R.; Alghwiri, A.A.; Romagnoli, C.; Messina, G.; Tancredi, V.; Padua, E.; Mercuri, N.B. Effect of segmental muscle vibration on upper extremity functional ability poststroke: A randomized controlled trial. *Medicine* 2019, 98. [CrossRef]
62. Toscano, M.; Celletti, C.; Viganò, A.; Altarocca, A.; Giuliani, G.; Jannini, T.B.; Mastria, G.; Ruggiero, M.; Maestruni, I.; Vicenzini, E.; et al. Short-Term Effects of Focal Muscle Vibration on Motor Recovery After Acute Stroke: A Pilot Randomized Sham-Controlled Study. *Front. Neurol.* 2019, 10. [CrossRef]
63. Volpe, D.; Giantin, M.G.; Fasano, A. A wearable proprioceptive stabilizer (Equistasi®) for rehabilitation of postural instability in Parkinson’s disease: A phase II randomized double-blind, double-dummy, controlled study. *PloS ONE* 2014, 9, e112065. [CrossRef] [PubMed]
64. Serio, F.; Minosa, C.; De Luca, M.; Conte, P.; Albani, G.; Peppe, A. Focal Vibration Training (Equistasi®) to Improve Posture Stability. A Retrospective Study in Parkinson’s Disease. *Sensors* 2019, 19, 2101. [CrossRef] [PubMed]
65. Peppe, A.; Paravati, S.; Baldassarre, M.G.; Bakkdounes, L.; Guiotto, A.; Pavadan, D.; Sawacha, Z.; Clerici, D.; Bottino, S.; Cau, N.; et al. Proprioceptive Focal Stimulation (Equistasi®) may improve the quality of gait in middle-moderate Parkinson’s disease patients. Double-blind, double-dummy, randomized, crossover, Italian Multicentric study. *Front. Neurol.* 2019, 10, 998. [CrossRef] [PubMed]
66. Spina, E.; Carotenuto, A.; Aceto, M.G.; Cerillo, I.; Silvestre, F.; Arace, F.; Paone, P.; Orefice, G.; Iodice, R. The effects of mechanical focal vibration (Equistasi®) on walking impairment in multiple sclerosis patients: A randomized, double-blinded vs placebo study. *Mult. Scler.* 2016, 22. [CrossRef]
67. Schirinzi, T.; Romano, A.; Favetta, M.; Sancesario, A.; Burattini, R.; Summa, S.; Della Bella, G.; Castelli, E.; Bertini, E.; Petrarca, M.; et al. Non-invasive focal mechanical vibrations delivered by wearable devices: An open-label pilot study in childhood Ataxia. *Front. Neurol.* 2018, 9, 849. [CrossRef]
68. Leonardi, L.; Aceto, M.G.; Marcotulli, C.; Arcuria, G.; Serrao, M.; Pierelli, F.; Paone, P.; Filla, A.; Roca, A.; Casali, C. A wearable proprioceptive stabilizer for rehabilitation of limb and gait ataxia in hereditary cerebellar ataxias: A pilot open-labeled study. *Neuro. Sci.* 2017, 38, 459–463. [CrossRef]
69. Cochrane, D. The acute effect of direct vibration on muscular power performance in master athletes. *Int. J. Sports Med.* 2016, 37, 144–148. [CrossRef]
70. Cochrane, D.J. Effectiveness of using wearable vibration therapy to alleviate muscle soreness. *Eur. J. Appl. Physiol.* 2017, 117, 501–509. [CrossRef]
71. Cochrane, D.J.; Cochrane, F.; Roake, J.A. An exploratory study of vibration therapy on muscle function in patients with peripheral artery disease. *J. Vasc. Surg.* 2020, 71, 1340–1345. [CrossRef]
72. Souron, R.; Besson, T.; Millet, G.Y.; Lapote, T. Acute and chronic neuromuscular adaptations to local vibration training. *Eur. J. Appl. Physiol.* 2017, 117, 1999–1964. [CrossRef]
73. Steyvers, M.; Levin, O.; Verschueren, S.M.; Swinnen, S.P. Frequency-dependent effects of muscle tendon vibration on corticospinal excitability: A TMS study. *Exp. Brain Res.* 2003, 151, 9–14. [CrossRef]
74. Necking, L.E.; Lundström, R.; Dahlín, L.B.; Lundborg, G.; Thornell, L.E.; Friden, J. Tissue displacement is a causative factor in vibration-induced muscle injury. *J. Hand Surg. Br. Eur. Vol.* 1996, 21, 753–757. [CrossRef]
75. Hagbarth, E.K.; Eklund, G. The effects of muscle vibration in spasticity, rigidity, and cerebellar disorders. *J. Neurol. Neurosurg. Psychiatry* 1968, 31, 207–213. [CrossRef]
76. Pietangelo, T.; Mancinelli, R.; Toniolo, L.; Cancellara, L.; Paoli, A.; Puglielli, C.; Iodice, P.; Doria, C.; Bosco, G.; d’Amelio, L.; et al. Effects of local vibrations on skeletal muscle trophy in elderly people: Mechanical, cellular, and molecular events. *Int. J. Mol. Med.* 2009, 24, 503–512. [CrossRef]
77. Nelson, M.C.; Murray, W.M.; Dewald, J.P.A. Motor Impairment-Related Alterations in Biceps and Triceps Brachii Fascicle Lengths in Chronic Hemiparetic Stroke. *Neurorehabil. Neural Repair* 2018, 32, 799–809. [CrossRef]
78. de Gooijer-van de Groep, K.L.; de Groot, J.H.; van der Krogt, H.; de Vlugt, E.; Arendzen, J.H.; Meskers, C.G. Early Shortening of Wrist Flexor Muscles Coincides With Poor Recovery After Stroke. *Neurorehabil. Neural Repair* 2018, 32, 645–654. [CrossRef]
79. Dutta, A.; Paulus, W.; Nitsche, M.A. Translational methods for non-invasive electrical stimulation to facilitate gait rehabilitation following stroke-the future directions. *Neurosci. Biomed. Eng.* 2013, 1, 22–33. [CrossRef]
80. Chae, J.; Quinn, A.; El-Hayek, K.; Santing, J.; Berezovski, R.; Harley, M. Delay in initiation and termination of tibialis anterior contraction in lower-limb hemiparesis: Relationship to lower-limb motor impairment and mobility. *Arch. Phys. Med. Rehabil.* **2006**, *87*, 1230–1234. [CrossRef]

81. Üstün, T.B.; Chatterji, S.; Bickenbach, J.; Kostanjsek, N.; Schneider, M. The International Classification of Functioning, Disability and Health: A new tool for understanding disability and health. *Disabil. Rehabil.* **2003**, *25*, 565–571.

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