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REVIEW

Clinical effectiveness of focal muscle vibration on gait and postural stability in individuals with neurological disorders: A systematic review

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Abstract

Background: Gait deficits and postural instability are common impairments among patients with neurological disorders. These impairments limit function independence and decrease activities of daily living. Focal muscle vibration (FMV) produces vibration signals affecting the nervous system. No systematic review has been published examining the influence of FMV on gait ability and postural stability in individuals with neurological disorders.

Objectives: This study aimed to investigate the effects of FMV on gait and postural stability parameters in individuals with neurological disorders.

Methods: PubMed, Scopus, PEDro, REHABDATA, web of science, CHAINAL, EMBASE, and MEDLINE were searched from inception to July 2021. The methodological quality of the selected studies was evaluated using the Physiotherapy Evidence Database (PEDro) scale.

Results: Five randomized controlled trials (RCTs) met the eligibility criteria. The scores on the PEDro scale ranged from seven to nine, with a median score of eight. The results showed evidence for the benefits and non-benefits of the FMV intervention on gait and postural stability in individuals with neurological disorders.

Conclusions: The FMV intervention is safe and well-tolerated in individuals with neurological disorders. The evidence for the effects of FMV on individuals with neurological disorders was limited. Further high-quality studies with long-term follow-up are strongly needed.

KEYWORDS
gait, neurological disorders, postural control, rehabilitation, vibration

1 | INTRODUCTION

Neurological disorders are a group of various conditions associated with various impairments, such as gait deficits and postural instability (Pozo-Cruz et al., 2012). These impairments contribute to develop of recurrent falls and reduce patients' physical activities (Speelman et al., 2011; Wenning et al., 1999). Reduction in physical activity is linked with various adverse consequences, such as osteoporosis, reduced cardiovascular fitness, constipation, and obesity, reducing functional independence (Speelman et al., 2011). Maintenance of postural control during standing depends not only on descending commands from the central nervous system but also on the

availability and the accuracy of somatosensory inputs from muscle, joint, skin and pressure receptors, and visual and vestibular inputs (Kavounoudias et al., 1998; Perry et al., 2000).

The available treatment options to improve gait ability and postural stability include numerous physical methods, such as physical activity (Persson et al., 2016), virtual reality (VR; Alashram, Annino, et al., 2020), whole-body vibration (WBV; Alashram, Padua, & Annino, 2019), task-oriented (Alashram, 2019), firm-textured surface (Palazzo et al., 2021), vestibular rehabilitation (Alashram, Annino, et al., 2020), rhythmic auditory stimulation (Alashram, Annino, & Mercuri, 2019). It has shown that for rehabilitation intervention to be effective, treatment needs to be highly repetitive, raise afferent input and be functional. Besides, engage the patients and encourage frequent practice (Pollock et al., 2014).

Focal muscle vibration (FMV) is a mechanical device that applies a vibratory stimulus to a specific muscle or tendon that influences the central nervous system (Alashram, Padua, et al., 2019). FMV generates the Ia inputs because of the activation primary ending of the muscle spindle (Roll et al., 1989), leading to alteration of corticospinal pathways (Steyvers et al., 2003). Several studies reported an increase of excitability in the primary motor cortex following low amplitude FMV in healthy people (Rosenkranz et al., 2003).

Many systematic reviews showed that FMV reduces spasticity (Alashram, Padua, et al., 2019), increases muscle perfusion (Fuller et al., 2012), and enhances muscle strength (Alghadir et al., 2018) in patients with various conditions. To date, no systematic reviews have been published examining the impact of FMV on gait and postural control. Therefore, this study aimed to investigate the effects of FMV on gait and postural control in patients with various neurological disorders.

2 | METHODS

2.1 | Search strategy

The preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement guidelines were followed (Moher et al., 2015). Two authors performed independent systematic reviews and data collection for appropriate studies published before July 2021 in PubMed, Scopus, PEDro, REHABDATA, web of science, CHAINAL, EMBASE, and MEDLINE databases (Figure 1). The key search terms were (Spinal cord injuries [MeSH] OR Stroke [MeSH] OR Cerebrovascular disorders [MeSH] OR Brain injuries [MeSH] OR Brain injuries, Traumatic [MeSH] OR Cerebral palsy [MeSH] OR Parkinson disease [MeSH] OR Multiple sclerosis [MeSH] OR Nervous system diseases [MeSH] OR Neurological disorders OR Neurological diseases) AND (FMV OR Local muscle vibration OR Segmental muscle vibration OR FMV OR Vibration) AND (Balance OR Postural balance [MeSH] OR Locomotion [MeSH] OR Ambulation OR Movement [MeSH] OR Gait [MeSH] OR Walking [MeSH]; Appendix A in Supporting Information S1).

2.2 | Eligibility criteria

Studies were included in the present systematic review if they (a) conducted on patients with a confirmed diagnosis for neurological disorders, (b) used FMV intervention, (c) compared with active or passive control interventions, (d) assessed gait and postural balance, (e) being a randomized controlled trial (RCT), and (f) written in English. Studies were excluded if they were (a) conducted on patients with non-neurological disorders, (b) used animal models, (c) used other vibration training methods, (d) used the medications as the main intervention, and (e) assessed upper limbs. Two reviewers individually performed the initial analysis of study selection by analyzing the titles and the abstracts. Wherever necessary, the whole text of the studies was reviewed, and all effort was assumed to avoid subjective bias (Pannucci & Wilkins, 2010). Any disagreement between the authors was discussed with the third author.

2.3 | Data extraction

The following data were extracted separately: (a) author and date of publication, (b) study design and participant characteristics, (c) FMV parameters and session details, (d) experimental group design, (e) control group design, and (f) side effects. The study characteristics were presented in Table 1. Table 2 displays the outcome measures of the selected studies. The following data were documented: (a) author and date of publication, (b) outcome measures, (c) assessment time, (d) experimental group, (e) control group, and (f) the results. The data were not pooled for meta-analysis because of the heterogeneity among the selected studies.

3 | METHODOLOGICAL QUALITY

Two authors evaluated the selected studies' methodological quality using the Physiotherapy Evidence Database scale (PEDro). The PEDro scale is a reliable a standard approach to evaluate the risk of bias in RCTs (Maher et al., 2003). It offers an overview of the internal and external validity of the studies (Maher et al., 2003). Four elements of the PEDro scale have been validated, while the other elements have face validity (Moher, 1999). Acceptable inter-rater reliability has been verified (Maher et al., 2003; Foley et al., 2006). Based on the PEDro statistics - PEDro (2021), https://pedro.org.au/english/learn/pedro-statistics/, a score of >5 is exhibited 'high quality. A score of 4–5 is exposed as fair quality, while a score of <4 is revealed as poor quality. Any disagreement between authors was

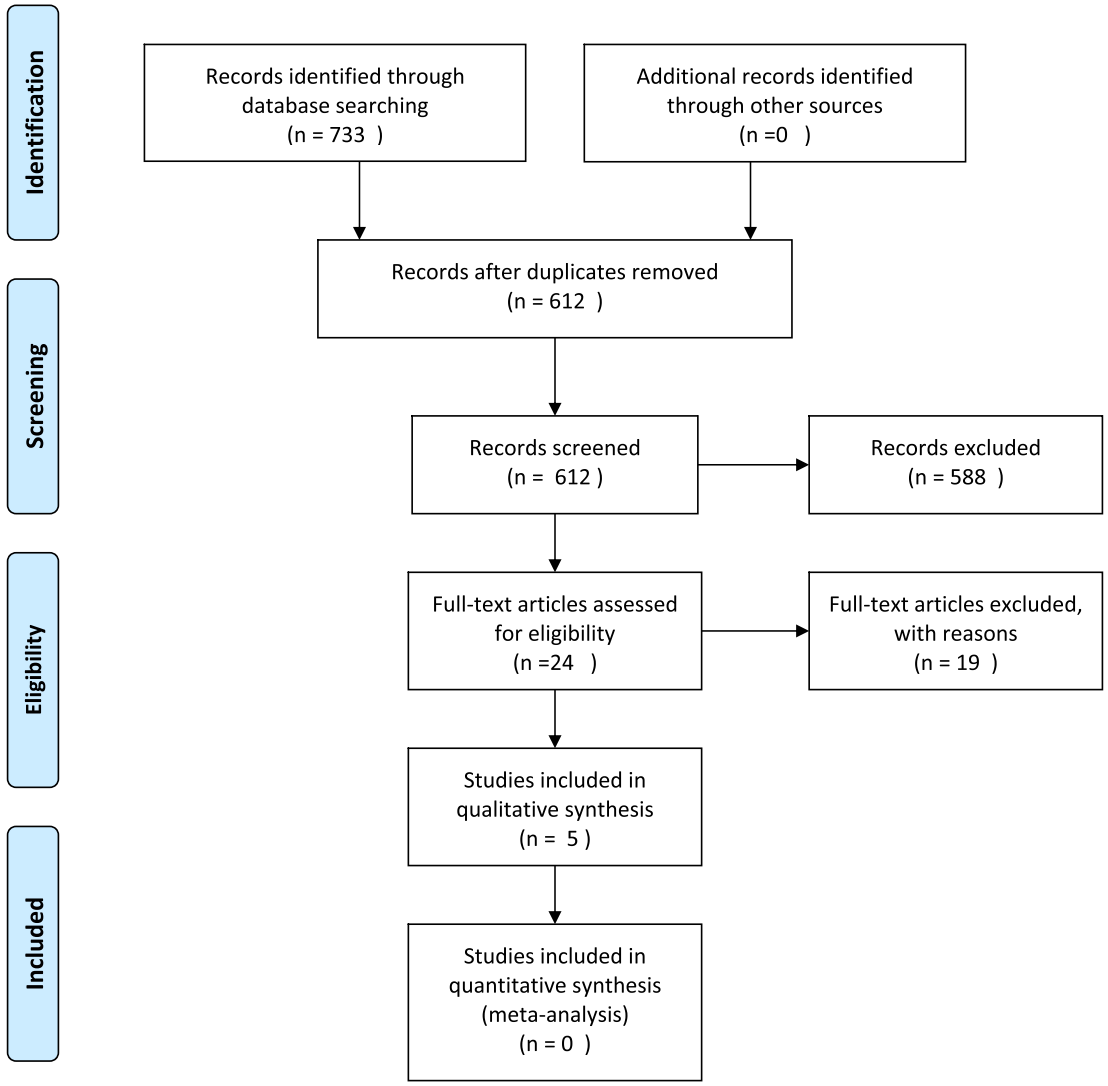

FIGURE 1 Summary of literature review process. *Source*: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for Systematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. https://doi.org/10.1371/journal.pmed1000097

resolved by discussion with the third author. Table 3 presents the methodological quality for the selected studies.

4 | RESULTS

4.1 | Study selection

An electronic search of PubMed (yielding 132 articles), SCOPUS (147), PEDro (17), REHABDATA (23), MEDLINE (101), CHAINAL (48), EMBASE (54), and Web of Science (211) produced a total of 733 studies. After removing duplicates, 612 studies were reviewed. Out of those, 588 studies were excluded because their abstracts showed that they did not match our inclusion criteria. Twenty-four studies were subjected to more detailed analysis. Nineteen studies were eliminated because they assessed upper limbs and were non-RCTs. A total of five studies were identified for the inclusion criteria in this systematic review. Figure 1 presents the process of the study selection.

4.2 | Study characteristics

4.2.1 | Participants

PICOS approach (Patients, Intervention, Control, Outcomes, and Subjects) was followed (Liberati, 2009). Two studies included patients with stroke (Lee et al., 2013; Paoloni et al., 2009), ataxia ($n = 1$; Özvar et al., 2020), multiple sclerosis (MS; $n = 1$; Ayvat et al., 2021), and Parkinson's disease (PD; $n = 1$; Camerota et al., 2016). A total of 149 patients with chronic neurological disorders, 26.85% of whom were females, were included in this systematic review. The mean age for all patients was 51.83 years old.

TABLE 1 Study characteristics

References	Participant's characteristics	FMV protocol	Experimental group	Control group	Side effects
Ayvat et al., 2021	Study design: RCT Population: MS Sample size: 33 Age: 36.96 Sex (M/F): 28/5 Disease duration (months): 114.26 EDSS: 2.91	Device: Vibrasens© (Techno Concept, Mane, France) Frequency: 50 Hz, 100 Hz Amplitude: 1 mm Vibration site: right and left gastrocnemius muscles FMV duration: 10 min (5 min each side) Session duration: 60 min Treatment duration: 3 days a week for 8 weeks. Session number: 24	Group 1: 50 Hz FMV +50-min CPT Group 2: 100 Hz FMV +50-min CPT	Group 3: 50-min CPT	No
Camerota et al., 2016	Study design: RCT Population: PD Sample size: 20 Age: 64.85 Sex (M/F): 8/12 Disease duration (months): 93 H & Y: 2.75	Device: Cro System; Nemoco SRL, Rome, Italy Frequency: 100 Hz Amplitude: 2–5 mm Vibration site: quadriceps and paraspinal muscles FMV duration: 60 min Session duration: 60 min Treatment duration: 1 day Session number: 1	FMV	Sham	No
Özvar et al., 2020	Study design: RCT Population: Ataxia (Spinocerebellar ataxia and MS) Sample size: 21 Age: 39.43 Sex (M/F): 9/12 Disease duration (months): >12	Device: Techno Concept, Mane, France Frequency: 80 Hz Amplitude: 1 mm Vibration site: right and left gastrocnemius muscles FMV duration: 10 min (5 min each side) Session duration: 10 min Treatment duration: 1 days Session number: 1	FNV	WBV (5-min, 30 Hz, 2 mm)	No
Paoloni et al., 2009	Study design: RCT Population: Stroke Sample size: 44 Age: 61.1 Sex (M/F): 39/5 Disease duration (months): 21	Device: Horus; Akropolis, Rome, Italy Frequency: 120 Hz Amplitude: 10 mm Vibration site: peroneus longus and tibialis anterior on hemiplegic side FMV duration: 30 min Session duration: 50 min, 80 min Treatment duration: 3 days a week for 4 weeks. Session number: 12	FMV+50-min CPT	50-min CPT CPT: stretching, muscle strengthening, balance, and overground walking training	No
Lee et al., 2013	Study design: RCT Population: Stroke Sample size: 31 Age: 54.52 Sex (M/F): 25/6 Disease duration (months): 53.44	Device: NR Frequency: 90 Hz Amplitude: 15 mm Vibration site: gastrocnemius muscle on hemiplegic side FMV duration: 30 min Session duration: 60 min Treatment duration: 5 days a week for 6 weeks. Session number: 30	FMV+30-min CPT	Sham FMV+30-min CPT	No

Abbreviations: CPT, conventional physiotherapy; EDSS, expanded disability status scale; FMV, focal muscle vibration; H&Y, Hoehn and Yahr Staging Scale; MS, multiple sclerosis; NA, not applicable; NR, not reported; RCT, randomized controlled trial; WBV, whole-body vibration.

TABLE 2 Outcome measures

References	Outcome measure	Assessment time	Experimental group	Control group	Results
Ayvat et al., 2021	[a]Bertec (Postural stability)–Los AP Bertec Balance Check Screener TM force platform system	At baseline and post intervention	Group 1: Pre: 15.02 (11.78–18.28) Post: 16.52 (15.56–18.20) Group 2: Pre: 13.53 (12.07–15.32) Post: 15.21 (15.21–17.11)	Group 3: Pre: 15.11 (13.12–17.71) Post: 16.56 (13.79–19.03)	No significant differences
	[a]Bertec (Postural stability)–Los ML	At baseline and post intervention	Group 1: Pre: 19.20 (15.75–22.48) Post: 22.92 (20.90–25.94) Group 2: Pre: 17.28 (15.77–21.88) Post: 19.68 (18.49–23.09)	Group 3: Pre: 21.47 (19.12–23.54) Post: 23.46 (17.26–23.99)	Significant improvements in both experimental groups
	[a]Bertec (Postural stability)–AP sway NSEO	At baseline and post intervention	Group 1: Pre: 0.49 (0.36–0.58) Post: 0.44 (0.39–0.54) Group 2: Pre: 0.44 (0.39–0.54) Post: 0.38 (0.36–0.62)	Group 3: Pre: 0.58 (0.38–0.61) Post: 0.45 (0.34–0.69)	No significant differences
	[a]Bertec (Postural stability)–AP sway NSEC	At baseline and post intervention	Group 1: Pre: 1.11 (0.68–1.32) Post: 0.54 (0.38–1.21) Group 2: Pre: 0.88 (0.68–1.20) Post: 0.68 (0.44–0.81)	Group 3: Pre: 0.67 (0.57–1.30) Post: 0.63 (0.47–1.00)	No significant differences
	[a]Bertec (Postural stability)–ML sway NSEO	At baseline and post intervention	Group 1: Pre: 0.23 (0.18–0.30) Post: 0.21 (0.12–0.28) Group 2: Pre: 0.23 (0.17–0.36) Post: 0.21 (0.18–0.25)	Group 3: Pre: 0.24 (0.15–0.48) Post: 0.23 (0.15–0.43)	No significant differences
	[a]Bertec (Postural stability)–ML sway NSEC	At baseline and post intervention	Group 1: Pre: 0.47 (0.30–0.69) Post: 0.21 (0.15–0.52) Group 2: Pre: 0.42 (0.22–0.67) Post: 0.22 (0.17–0.28)	Group 3: Pre: 0.35 (0.17–0.42) Post: 0.29 (0.21–0.36)	Significant improvements in both experimental groups
	GAITRite Analysis System (Gait)–Velocity (cm/s)	At baseline and post intervention	Group 1: Pre: 104.74 ± 22.06 Post: 115.78 ± 27.27 Group 2: Pre: 100.38 ± 20.91 Post: 115.75 ± 17.42	Group 3: Pre: 102.66 ± 18.93 Post: 118.55 ± 17.19	Significant improvements in both experimental groups
	GAITRite Analysis System (Gait)–Step length (cm)	At baseline and post intervention	Group 1: Pre: 56.14 ± 7.90 Post: 61.43 ± 8.21 Group 2: Pre: 55.44 ± 5.96 Post: 59.86 ± 6.31	Group 3: Pre: 56.10 ± 5.67 Post: 59.89 ± 4.86	Significant improvements in both experimental groups
	GAITRite Analysis System (Gait)–Double support	At baseline and post intervention	Group 1: Pre: 27.81 ± 3.19 Post: 25.89 ± 4.17 Group 2: Pre: 29.56 ± 5.10 Post: 27.45 ± 4.81	Group 3: Pre: 28.41 ± 5.59 Post: 26.00 ± 3.90	Significant improvements in group 1

(Continues)

TABLE 2 (Continued)

References	Outcome measure	Assessment time	Experimental group	Control group	Results
	GAITRite Analysis System (Gait)–Single support (% GC)	At baseline and post intervention	Group 1: Pre: 36.00 ± 1.69 Post: 36.97 ± 2.13 Group 2: Pre: 34.95 ± 2.79 Post: 35.96 ± 2.29	Group 3: Pre: 35.69 ± 2.63 Post: 36.95 ± 1.94	No significant differences
	GAITRite Analysis System (Gait)–Stance (%GC)	At baseline and post intervention	Group 1: Pre: 64.01 ± 1.68 Post: 63.03 ± 2.16 Group 2: Pre: 65.06 ± 2.79 Post: 64.04 ± 2.29	Group 3: Pre: 64.30 ± 2.63 Post: 63.04 ± 1.94	No significant differences
	GAITRite Analysis System (Gait)–Swing (%GC)	At baseline and post intervention	Group 1: Pre: 35.99 ± 1.69 Post: 36.97 ± 2.15 Group 2: Pre: 34.95 ± 2.79 Post: 34.95 ± 2.79	Group 3: Pre: 35.69 ± 2.62 Post: 36.79 ± 2.04	Significant improvements in group 1
	GAITRite Analysis System (Gait)–Base of support (cm)	At baseline and post intervention	Group 1: Pre: 9.69 ± 2.31 Post: 8.68 ± 2.02 Group 2: Pre: 10.11 ± 3.87 Post: 9.15 ± 3.94	Group 3: Pre: 10.87 ± 2.55 Post: 10.27 ± 2.74	Significant improvements in both experimental groups
Camerota et al., 2016	[b]Optoelectronic system with passive markers (Gait)–Velocity (m/s)	At baseline (T0), 24 h (T1), 1 week (T2), and 3 weeks (T3) after the session	T0: 0.63 (0.50–1.03) T1: 0.80 (0.50–1.30) T2: 0.83 (0.60–1.07) T3: 0.73 (0.50–1.17)	T0: 0.88 (0.37–1.20) T1: 0.90 (0.30–1.20) T2: 0.83 (0.50–1.17) T3: 0.90 (0.60–1.17)	Significant improvements at T1, T2, and T3
	[b]Optoelectronic system with passive markers (Gait)–Step length (m)	At baseline (T0), 24 h (T1), 1 week (T2), and 3 weeks (T3) after the session	T0: 0.41 (0.28–0.58) T1: 0.44 (0.25–0.66) T2: 0.46 (0.38–0.65) T3: 0.44 (0.28–0.59)	T0: 0.49 (0.31–0.61) T1: 0.50 (0.40–0.61) T2: 0.49 (0.33–0.58) T3: 0.49 (0.36–0.57)	Significant improvements at T1, T2, and T3
	[b]Optoelectronic system with passive markers (Gait)–Stride length (m)	At baseline (T0), 24 h (T1), 1 week (T2), and 3 weeks (T3) after the session	T0: 0.80 (0.58–1.15) T1: 0.84 (0.66–1.30) T2: 0.86 (0.78–1.26) T3: 0.87 (0.64–1.17)	T0: 0.99 (0.91–1.08) T1: 0.96 (0.89–1.13) T2: 1.02 (0.86–1.16) T3: 0.96 (0.81–1.08)	Significant improvements at T1, T2, and T3
	[b]Optoelectronic system with passive markers (Gait)-swing velocity (m/s)	At baseline (T0), 24 h (T1), 1 week (T2), and 3 weeks (T3) after the session	T0: 1.79 (1.20–2.73) T1: 1.95 (1.43–3.10) T2: 1.97 (1.53–2.53) T3: 1.90 (1.27–2.80)	T0: 2.14 (1.10–2.70) T1: 2.20 (1.67–2.80) T2: 2.21 (1.43–2.73) T3: 2.21 (1.53–2.73)	Significant improvements at T1, T2, and T3
	[b]Optoelectronic system with passive markers (Gait)–Step width (m)	At baseline (T0), 24 h (T1), 1 week (T2), and 3 weeks (T3) after the session	T0: 0.17 (0.13–0.19) T1: 0.17 (0.15–0.19) T2: 0.16 (0.15–0.19) T3: 0.17 (0.15–0.19)	T0: 0.17 (0.14–0.22) T1: 0.17 (0.14–0.25) T2: 0.17 (0.14–0.22) T3: 0.18 (0.14–0.21)	No significant differences
	[b]Optoelectronic system with passive markers (Gait)–Cadence (step/min)	At baseline (T0), 24 h (T1), 1 week (T2), and 3 weeks (T3) after the session	T0: 61.61 (56.03–65.17) T1: 60.67 (56.10–66.40) T2: 60.70 (57.13–65.63) T3: 61.13 (55.97–66.27)	T0: 61.13 (55.97–66.27) T1: 60.16 (57.57–62.77) T2: 60.16 (57.57–62.77) T3: 60.70 (56.87–64.07)	No significant differences
Özvar et al., 2020	Forward LoS (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 9.36 ± 4.53 T1: 8.65 ± 3.64 T2: 8.82 ± 2.06	T0: 8.79 ± 2.58 T1: 8.79 ± 2.58 T2: 9.07 ± 2.52	No significant differences
	Backward LoS (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 6.1 ± 2.15 T1: 7.86 ± 1.39 T2: 7.51 ± 2.17	T0: 6.44 ± 2.25 T1: 6.44 ± 2.25 T2: 6.97 ± 2.01	Significant improvements at 1 and 60 min

TABLE 2 (Continued)

References	Outcome measure	Assessment time	Experimental group	Control group	Results
	Left LoS (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 10.75 ± 2.53 T1: 12.72 ± 2.01 T2: 13.21 ± 1.53	T0: 11.69 ± 2.25 T1: 11.99 ± 2.79 T2: 12.27 ± 2.11	Significant improvements at 1 and 60 min
	Los stability (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 78.4 ± 11.69 T1: 83.44 ± 8.61 T2: 82.64 ± 11.25	T0: 75.32 ± 18.36 T1: 70.6 ± 19.7 T2: 78.39 ± 9.83	Significant improvements at 1 min
	Right LoS (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 11.75 ± 2.36 T1: 12.68 ± 2.46 T2: 12.85 ± 2.2	T0: 12.39 ± 2.99 T1: 12.46 ± 2.73 T2: 13.03 ± 2.47	Significant improvements at 1 and 60 min
	APSR-eyes open on a firm surface (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 0.9 ± 0.37 T1: 1.07 ± 0.56 T2: 0.97 ± 0.47	T0: 0.91 ± 0.4 T1: 1.15 ± 0.56 T2: 1.02 ± 0.45	No significant differences
	APSR-eyes closed on a firm surface (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 1.32 ± 0.78 T1: 1.29 ± 0.77 T2: 1.2 ± 0.74	T0: 1.32 ± 0.75 T1: 1.5 ± 0.96 T2: 1.23 ± 0.77	No significant differences
	LSR–eyes open on a firm surface (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 0.48 ± 0.29 T1: 0.48 ± 0.29 T2: 0.57 ± 0.54	T0: 0.5 ± 0.34 T1: 0.76 ± 0.63 T2: 0.74 ± 0.71	No significant differences
	LSR-eyes closed on a firm surface (cm) (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 0.62 ± 0.61 T1: 0.61 ± 0.63 T2: 0.58 ± 0.61	T0: 0.65 ± 0.56 T1: 0.72 ± 0.63 T2: 0.53 ± 0.42	No significant differences
	OLST right–EO (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 8.27 ± 12.2 T1: 9.85 ± 10.45 T2: 13.22 ± 18.77	T0: 10.02 ± 11.64 T1: 12.39 ± 20.21 T2: 10.9 ± 13.06	Significant improvements at 1 and 60 min
	OLST left–EO (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 13.22 ± 18.77 T1: 12.73 ± 16.73 T2: 17.09 ± 22.27	T0: 12.12 ± 15.77 T1: 12.19 ± 15 T2: 13.17 ± 14.29	Significant improvements at 1 and 60 min
	OLST right–EC (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 1.82 ± 0.96 T1: 2.47 ± 2.24 T2: 2.47 ± 2.24	T0: 2.07 ± 1.34 T1: 3.12 ± 3.07 T2: 2.82 ± 2.45	Significant improvements at 1 and 60 min
	OLST left–EC (Postural stability)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 2.14 ± 1.68 T1: 2.14 ± 1.68 T2: 3.02 ± 2.8	T0: 1.99 ± 1.28 T1: 3.02 ± 2.9 T2: 3.05 ± 2.37	Significant improvements at 1 and 60 min
	Base of support–right (cm) (Gait)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 12.72 ± 4.92 T1: 13.87 ± 4.65 T2: 13.05 ± 4.67	T0: 13.08 ± 4.82 T1: 12.5 ± 4.65 T2: 12.84 ± 4.27	Significant improvements at 1 min
	Base of support–left (cm) (Gait)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 12.66 ± 4.96 T1: 13.79 ± 4.71 T2: 13.05 ± 4.48	T0: 13.15 ± 4.83 T1: 12.6 ± 4.56 T2: 13.15 ± 4.3	Significant improvements at 1 min

(Continues)

TABLE 2 (Continued)

References	Outcome measure	Assessment time	Experimental group	Control group	Results
	Velocity (cm/s) (Gait)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 103.59 ± 24.09 T1: 99.1 ± 22.72 T2: 105.04 ± 25.36	T0: 107.72 ± 24.54 T1: 106.51 ± 21.26 T2: 112.37 ± 25.06	Significant improvements at 1 and 60 min
	Cadence (steps/min) (Gait)	At baseline (T0), 1 h (T1), and 60 min after the intervention (T2)	T0: 107.76 ± 12.9 T1: 105.62 ± 12.74 T2: 107.68 ± 14.48	T0: 109.04 ± 14.48 T1: 108.37 ± 11.8 T2: 111.21 ± 13.24	No significant differences
Paoloni et al., 2009	Toe-off normal (%) (Gait)	At baseline and post intervention	Pre: 67.0 ± 6.2 Post: 64.1 ± 5.7	Pre: 67.2 ± 9.5 Post: 65.7 ± 10.1	No significant differences
	Toe-off paretic (%) (Gait)	At baseline and post intervention	Pre: 62.6 ± 5.8 Post: 59.6 ± 5.5	Pre: 65.1 ± 6.2 Post: 64.1 ± 8.0	Significant improvements
	Cadence (step/min) (Gait)	At baseline and post intervention	Pre: 75.1 ± 12.0 Post: 80.4 ± 13.5	Pre: 71.9 ± 21.5 Post: 74.1 ± 21.7	No significant differences
	Step length normal (m) (Gait)	At baseline and post intervention	Pre: 0.34 ± 0.12 Post: 0.40 ± 0.11	Pre: 0.35 ± 0.09 Post: 0.37 ± 0.10	No significant differences
	Step length paretic (m) (Gait)	At baseline and post intervention	Pre: 0.36 ± 0.11 Post: 0.39 ± 0.09	Pre: 0.35 ± 0.07 Post: 0.35 ± 0.08	No significant differences
	Stride length normal (m) (Gait)	At baseline and post intervention	Pre: 0.71 ± 0.20 Post: 0.82 ± 0.18	Pre: 0.69 ± 0.14 Post: 0.71 ± 0.15	Significant improvements
	Stride length paretic (m) (Gait)	At baseline and post intervention	Pre: 0.70 ± 0.19 Post: 0.79 ± 0.17	Pre: 0.70 ± 0.13 Post: 0.70 ± 0.13	Significant improvements
	Step width normal (m) (Gait)	At baseline and post intervention	Pre: 0.70 ± 0.13 Post: 0.17 ± 0.04	Pre: 0.19 ± 0.03 Post: 0.19 ± 0.04	No significant differences
	Step width paretic (m) (Gait)	At baseline and post intervention	Pre: 0.18 ± 0.05 Post: 0.17 ± 0.04	Pre: 0.20 ± 0.04 Post: 0.19 ± 0.02	No significant differences
	Swing velocity normal (m/s) (Gait)	At baseline and post intervention	Pre: 1.32 ± 0.34 Post: 1.53 ± 0.39	Pre: 1.33 ± 0.38 Post: 1.35 ± 0.29	Significant improvements
	Swing velocity paretic (m/s) (Gait)	At baseline and post intervention	Pre: 1.19 ± 0.36 Post: 1.35 ± 0.40	Pre: 1.22 ± 0.48 Post: 1.23 ± 0.42	No significant differences
	Gait speed (m/s) (Gait)	At baseline and post intervention	Pre: 0.44 ± 0.13 Post: 0.53 ± 0.13	Pre: 0.44 ± 0.21 Post: 0.46 ± 0.21	Significant improvements
Lee et al., 2013	Distance eyes open (cm) (Postural sway)	At baseline and post intervention	Pre: 70.86 ± 34.17 Post: 58.95 ± 22.30	Pre: 67.27 ± 18.60 Post: 68.07 ± 16.12	Significant improvements
	Distance eyes close (cm) (Postural sway)	At baseline and post intervention	Pre: 91.97 ± 43.75 Post:71.31±	Pre: 80.83 ± 20.92 Post: 80.48 ± 21.56	Significant improvements
	Velocity eyes open (cm/m) (Postural sway)	At baseline and post intervention	Pre: 2.36 ± 1.14 Post: 1.97 ± 0.74	Pre: 2.24 ± 0.62 Post: 2.27 ± 0.54	Significant improvements
	Velocity eyes close (cm/m) (Postural sway)	At baseline and post intervention	Pre: 3.07 ± 1.46 Post:2.38 ± 1.05	Pre: 2.69 ± 0.70 Post: 2.68 ± 0.72	Significant improvements
	Gait speed (cm/s) (Gait)	At baseline and post intervention	Pre: 37.79 ± 26.04 Post: 52.38 ± 31.38	Pre: 38.25 ± 17.75 Post: 41.10 ± 17.20	Significant improvements
	Cadence (step/min) (Gait)	At baseline and post intervention	Pre: 27.49 ± 18.94 Post: 35.95 ± 21.71	Pre: 28.92 ± 14.00 Post: 30.74 ± 11.31	Significant improvements
	Step length paretic (m) (Gait)	At baseline and post intervention	Pre: 31.36 ± 13.83 Post: 39.26 ± 14.31	Pre: 28.89 ± 13.29 Post: 32.53 ± 13.26	Significant improvements

TABLE 2 (Continued)

References	Outcome measure	Assessment time	Experimental group	Control group	Results
	Single limb support paretic (s) (Gait)	At baseline and post intervention	Pre: 0.47 ± 0.18 Post: 0.59 ± 0.16	Pre: 0.42 ± 0.20 Post: 0.43 ± 0.16	Significant improvements

Abbreviations: 10MWT, 10 m walk test; AP, anterior posterior; APSR, anterior-posterior sway range; EC, eyes closed; EO, eyes open; GC, gait cycle; Los, limit of stability; LSR, lateral sway range; ML, mediolateral; NSEC, normal stability eyes closed; NSEO, normal stability eyes open; OLST, one-leg stance test.

[a]Median (25%–75% IQR).

[b]Median and range (min-max).

TABLE 3 Methodological quality scores

Reference	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	<15% dropouts	Intention to treat analysis	Between-group differences reported	Point estimate and variability reported	Total (0–10)
Ayvat et al., 2021	[a]		[a]			[a]	[a]	[a]	[a]	[a]	7
Camerota et al., 2016	[a]	[a]	[a]			[a]	[a]	[a]	[a]	[a]	8
Özvar et al., 2020	[a]	[a]	[a]			[a]	[a]	[a]	[a]	[a]	8
Paoloni et al., 2009	[a]	[a]	[a]			[a]	[a]	[a]	[a]	[a]	8
Lee et al., 2013	[a]	[a]	[a]		[a]	[a]	[a]	[a]	[a]	[a]	9

[a]Low risk of bias.

4.3 | Study design

In the study by Ayvat et al. (2021), all patients received 50-min conventional physiotherapy (CPT) intervention. The CPT intervention consists of mat exercises, functional exercises, and static and dynamic balance activities. Patients in the experimental groups received 50 Hz or 100 Hz FMV using Vibrasens© (Techno Concept, Mane, France) with amplitude set at 1 mm. FMV was applied over right and left gastrocnemius muscles (5 min each). In total, all patients received three sessions per week for 8 weeks.

Moreover, patients in the study by Camerota et al. (2016) received a single session of FMV experimental or sham stimulation control intervention using (Cro System; Nemoco SRL). The FMV intervention was applied over quadriceps and paraspinal muscles for 60 min with a 100 Hz frequency and 2–5 mm amplitude.

Furthermore, in the study by Özvar et al. (2020), patients with ataxia received a single session of either FMV experimental or WBV control intervention. The FMV in the experimental group was applied over right and left gastrocnemius muscles (5 min each) using (Techno Concept) with an 80 Hz frequency and 1 mm amplitude.

Additionally, in the study by Paoloni et al. (2009), patients with stroke received a 50-min CPT intervention. The CPT intervention consists of stretching, muscle strengthening, balance, and overground walking training. Patients in the experimental groups received another 30-min FMV using (Horus) with a frequency set at 120 Hz and amplitude at 10 mm. In total, all patients received three sessions per week for 4 weeks.

Finally, in the study by Lee et al. (2013), patients with stroke received 30-min CPT. The CPT intervention consists of occupational therapy, functional electrical stimulation, and therapeutic exercises for lower extremity muscle strength and gait. After that, patients in the experimental group received 30-min FMV with a frequency of 90 Hz and amplitude of 15 mm, whereas patients in the control groups received 30-min sham stimulation. In total, all patients received five sessions per week for 6 weeks. The device details were not reported.

4.4 | Outcome measures

The included studies used various outcome measures to measure postural stability and gait in patients with neurological disorders.

4.5 | Postural stability

In the study by Ayvat et al. (2021), the authors evaluated the postural stability using the Bertec Balance Check Screener™ force platform system (Bertec Co.). The limits of stability (LoS) were assessed on a firm surface in four directions (forward, backward, left, right).

Postural sways were evaluated in the anteroposterior (AP) and mediolateral (ML) directions in two different conditions (i.e. normal stability eyes open and closed). Moreover, Özvar et al. (2020) measured the LoS and postural stability using A Balance Check Screener (model BP5050; Bertec) force plate system. The limits of stability (LoS) in four directions (forward, backward, left, right) with a firm surface was evaluated. Postural sways in the anteroposterior (APSR) and mediolateral (LSR) directions in four different conditions (eyes open on a firm surface, eyes closed on a firm surface, eyes open on a foam surface, and eyes closed on a foam surface) were measured. Finally, Lee et al. (2013) measured the postural sway velocity and distance in the standing posture under the eyes-open and closed conditions using the force platform (Point Distribution Model Multifunction Force Measuring Plate).

4.6 | Gait

Ayvat et al. (2021) measured gait parameters using the GAITRite Analysis System (CIR System Inc.). The velocity, step length, percentage of gait cycle spent in double and single support, stance and swing phase, and the base of support per walking trial were recorded. Moreover, Lee et al. (2013) measured gait ability using an electrical walkway system (GAITRite, CIR System Inc.). Gait speed, cadence, paretic side-step length, and single-limb support time were measured. Additionally, Özvar et al. (2020) evaluated the time-distance Characteristics of gait using the GAITRite (CIR System Inc.). The base of support (cm), velocity (cm/s), and cadence (steps/min) parameters were measured. Furthermore, Camerota et al. (2016) assessed gait using an optoelectronic system with passive markers (ELITE 2002; BTS) with a sampling rate of 100 Hz and two camera video systems (BTS, Italy) synchronized with the system and the platforms for video recording. Finally, Paoloni et al. (2009) evaluated gait parameters using the ELITE stereophotogrammetric system (BTS, Milan, Italy) with eight infrared video cameras (TVC; BTS) for the acquisition of kinematic variables.

4.7 | Effects of FMV on postural stability in patients with neurological disorders

In the study by Ayvat et al. (2021), the results showed significant improvements in the loss of mediolateral stability (los-ML) and mediolateral eye closed normal stability (ML-NSEC) after the FMV intervention. There are no significant differences between groups in the loss of anteroposterior stability (los-AP), anteroposterior sway normal stability eye open (AP-NSEO), anteroposterior sway normal stability eye close (AP-NSEC), and mediolateral sway normal stability eye open (ML-NSEO). Moreover, Özvar et al. (2020) reported significant improvements in the backward loss of stability (backward-los), left loss of stability (left-los), right loss of stability (right-los), right eye open-one-leg stance test (OLST right–EO), right eye close-one-leg stance test (OLST right–EC), left eye open-one-leg stance test (OLST left–EO), and left eye close-one-leg stance test (OLST left–EC) at 1 and 60 min post-intervention. Besides, total loss of stability (total-los) at 1-min post-intervention. No significant differences between groups in the forward loss of stability (forward-los), anterior-posterior sway range-eyes open on a firm surface, anterior-posterior sway range-eyes closed on a firm surface, lateral sway range-eyes open on a firm surface, and lateral sway range-eyes closed on a firm surface. Furthermore, Lee et al. (2013) demonstrated significant improvements in the postural sway velocity (eyes open and eyes close) and distance (eyes open and eyes close) after the experimental intervention.

4.8 | Effects of FMV on gait in patients with neurological disorders

In the study by Ayvat et al. (2021), there were significant improvements in both experimental groups in the gait velocity, step length, and base of support. Double support and swing phase (% gait cycle) were improved after 50 Hz FMV plus 50-min CPT intervention. No significant differences in the single support and stance phase (% gait cycle) were reported. Moreover, in the study by Camerota et al. (2016), there were significant improvements in the gait velocity, step length, stride length, and swing velocity at least 1 week after experimental intervention were reported. No significant differences between groups in the step width and cadence were demonstrated. Furthermore, in the study by Özvar et al. (2020), there were significant improvements in the gait velocity and right and left base of support after experimental intervention were reported. No significant difference in cadence was reported. Additionally, in the study by Paoloni et al. (2009), there were significant improvements in the toe-off of paretic limb, Stride length of paretic and normal limbs, swing velocity of normal limb, and gait speed after experimental intervention were reported. No significant differences in the toe-off of normal limb, cadence, step length of normal and paretic limbs, step width normal of normal and paretic limbs, and swing velocity of the paretic limb. Finally, in the study by Lee et al. (2013), there were significant improvements in the gait speed, cadence, step length of paretic limb, and single limb support of paretic limb after experimental intervention were reported.

4.9 | Adverse effects or side effects

No adverse effects or side effects were demonstrated after the FMV interventions in the selected studies.

5 | METHODOLOGICAL QUALITY

The score on the PEDro scale ranged from seven to nine, with a median of eight. Overall, one study met nine criteria (Lee et al., 2013), three studies met eight criteria (Camerota et al., 2016; Özvar et al.,

2020; Paoloni et al., 2009), and one study met seven criteria (Ayvat et al., 2021). Table 3 presents the methodological quality scores for the selected studies.

6 | DISCUSSION

To our knowledge, this is the first review to examine the influences of FMV intervention on gait and postural parameters in individuals with neurological disorders. The main findings showed evidence for the benefits of FMV on some gait and postural stability parameters following neurological disorders. The FMV generates the Ia inputs because of the activation muscle spindle primary ending (Roll et al., 1989). Alteration of the corticospinal pathway excitability results in activation of Ia inputs by FMV (Steyvers et al., 2003). It is done by facilitating inputs and modulating intracortical inhibiting to the primary motor cortex (M1) in the brain (Rosenkranz et al., 2003; Rosenkranz & Rothwell, 2006). Vibrating a specific muscle can increase the motor evoked potential (MEP) recorded from the muscle at rest (Mileva et al., 2008). This suggested the progress of corticospinal excitability changes during vibration (Rosenkranz & Rothwell, 2006; Smith & Brouwer, 2005). FMV affects the proprioceptive input and develops its role in sustaining balance and promoting walking (Lee et al., 2013; Paoloni et al., 2009). Spasticity and muscle weakness consider the main factors that affect gait ability and postural control in patients with neurological disorders (Graham, 2013; Horlings et al., 2008). It has been shown that vibrated antagonist muscle may reduce agonist muscle spasticity (Alashram, Annino, & Mercuri, 2019) and improve muscle strength (Alghadir et al., 2018).

This review incorporates five RCTs with high methodological quality. The selected studies in this review had several limitations that expose them to potential bias, including failing to be concealed allocation (Ayvat et al., 2021), blinding of patients (Ayvat et al., 2021; Camerota et al., 2016; Lee et al., 2013; Özvar et al., 2020; Paoloni et al., 2009), and blinding of therapists (Ayvat et al., 2021; Camerota et al., 2016, Özvar et al., 2020; Paoloni et al., 2009). On the other hand, Except for Paoloni et al. (2009), the sample sizes were small among the included studies, decreasing the statistical power and not allowing generalization of the results to the wider patient populations.

Three studies combined FMV with CPT (Ayvat et al., 2021; Lee et al., 2013; Paoloni et al., 2009), whereas two studies used FMV alone during treatment intervention (Camerota et al., 2016; Özvar et al., 2020). The results among the included studies were heterogeneous.

The included studies showed improvements in the loss of stability (40%), gait velocity (100%), step length (75%), single limb support (83.3%), stance phase (0%), double support (100%), swing phase (100%), base of support (100%), stride length (100%), swing velocity (66.67%), step width (0%), cadence (25%), toe-off (50%), distance (100%). Paoloni et al. (2009) speculate the improvement in gait speed occurs due to an increase in dorsiflexor muscles strength. Further, Lee et al. (2013) demonstrate that vibrated ankle and foot may alternate anticipatory movement for postural control results in greater enhancement for postural sway. Besides, focal vibration stimulus to weight-bearing and weight-shift training could have enabled patients to exert efforts, thereby improving gait ability. Moreover, Ayvat et al. (2021) showed that spasticity reduction improves many gaits and postural control spatiotemporal parameters. Two of the included studies investigated the immediate effects (single session) of FMV on gait and postural stability in patients with Parkinson's disease (Camerota et al., 2016) and ataxia (Özvar et al., 2020). Özvar et al. (2020) explain the improvements in right and left loss of stability result from neuromuscular activation. As well, Camerota et al. (2016) suggest that FMV induces sensory afferent inputs to the central nervous system (CNS) and improves the functional activation of neuronal generators responsible for locomotion in the CNS through restored sensorimotor integration.

Three studies used various force platform systems to assess postural stability (Ayvat et al., 2021; Lee et al., 2013; Özvar et al., 2020). Force platform systems provide objective and quantitative assessments for postural control impairments in patients with neurological disorders (Harro et al., 2018). On the other hand, three studies (Ayvat et al., 2021; Lee et al., 2013; Özvar et al., 2020) used the GAITRite system to assess gait parameters. The GAITRite system has excellent reliability for most temporospatial gait parameters in both young (intraclass correlation coefficient; ICC = 0.88–0.92) and older subjects (ICC = 0.88–0.91; Menz et al., 2004) and stroke patients (ICC = 0.72–0.94; Kuys et al., 2011). Camerota et al. (2016) and Paoloni et al. (2009) used ELITE optoelectronic systems to assess gait parameters. The ELITE optoelectronic system has excellent reliability (ICC = 0.90–0.98) in patients with various disorders (Alghadir et al., 2018).

Using different treatment protocols of FMV, including different parameters, vibration site, and vibration devices did not allow finding optimal treatment parameters for treating several impairments in patients with neurological disorders. Further, because of the heterogeneity of treatment protocols, the population who most likely would benefit from the intervention and the optimal treatment protocols remain unclear. Furthermore, the long-term effects of FMV remain ambiguous. As well, the effects of FMV on occupational performance following neurological disorders were not understood. Additionally, the effects of FMV on gait and postural control in patients with other neurological disorders (e.g., traumatic brain injury, cerebral palsy, Alzheimer disease) were not studied yet.

Recently, many interventions such as virtual reality (VR; Alashram, Annino, & Mercuri, 2019), rhythmic auditory stimulation (Alashram, Annino, et al., 2020), whole-body vibration (Alashram, Annino, & Mercuri, 2019), Lokomat (Alashram et al., 2021), task-oriented (Alashram, Padua, & Annino, 2019), firm-textured (Palazzo et al., 2021), and vestibular rehabilitation therapy (Alashram, Annino, et al., 2020), have proven their effects on postural control and gait post neurological disorders. Combining FMV with one of these interventions may show significant effects on gait ability and postural control in individuals with neurological disorders than FMV alone.

Further high-quality studies with large sample sizes and long-term follow-up are warranted.

The current systematic review has many strengths in terms of methodology. First, a comprehensive literature search from eight databases/resources was conducted to identify potential trials. Second, only RCTs reporting validated outcome measurement instruments were considered, which allowed us to enhance the interpretability of the results. Nevertheless, there are a few limitations among included trials that should be highlighted. The systematic search process was limited by studies published in English, which could lead to the overestimation of training effects (Higgins & Altman, 2008). As the intervention protocols used differed on more than one FMV parameter (amplitude, treatment duration, and frequency), it is difficult to make meaningful comparisons across studies and delineate the independent effects of different FMV parameters. Meta-analysis was not possible due to the heterogeneity of the studies.

7 | CONCLUSIONS

The FMV intervention is safe and well-tolerated in patients with neurological disorders. The evidence for the effects of FMV on patients with neurological disorders was limited. Further studies with long-term follow-up are strongly needed.

AUTHOR CONTRIBUTIONS

Anas R. Alashram: Writing the original manuscript. Elvira Padua: Data search. Cristian Romagnoli: Data extraction. Manikandan Raju: Data extraction. Giuseppe Annino: Review and revise the manuscript.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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