EFFECT OF FOCAL MUSCLE VIBRATION THERAPY ON REACTION TIMING, SPASTICITY, IMPAIRMENT AND VOLUNTARY CONTROL OF UPPER LIMB FUNCTION IN TRAUMATIC BRAIN INJURY SUBJECTS

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ABSTRACT

Background & purpose: Traumatic brain injury (TBI) is a dysfunction of the brain cells that disturbs the normal brain function and impacting individuals and society with long- term impairments. Along with the emotional and behavioral consequences, other common manifestation includes impaired hand functions as a result of spasticity, increased response time, and loss of volitional control. The current study aimed to assess the effect of focal muscle vibration therapy (FMVT) on reaction timing, spasticity, impairment and voluntary control of hand functions in TBI subjects.

Materials & Methods: An OPD and multispecialty hospital based randomized controlled trial (RCT) was conducted. Sixty participants meeting the inclusion criteria were selected and allocated into experimental and control group. The experimental study received FMVT and modified constraint movement therapy (M-CIMT) for 6 weeks. In contrast, the control group underwent sustained stretching, PNF hold-relax, and M-CIMT for a period of 6 weeks. Post- assessments were conducted at week 3 and 6.

Result: Following the 6 weeks protocol, the study findings indicated improvement in both the groups for all four variables. The group that received FMVT showed significant improvement in all the clinical outcome measures. The conventional therapy group also showed improvements, though less pronounced. When comparing the two groups, FMVT demonstrated superior efficacy over the control group across all the outcome measures.

Conclusion: FMVT has been proven to significantly improve hand functions. Additionally, the study explored a relatively novel outcome of reaction timing, providing valuable insights on its impact in TBI population.

INTRODUCTION

TBI disrupts the brain function following an external insult to the brain in the form of vehicular accidents, falls or assaults [1], comprising of a wide array of temporary or a more permanent consequences [2]. It is a key cause for an increased disability and death toll globally with an estimated population of roughly 50-74 million affected by TBI [3], causing a major financial load on the society.

The incidence of TBI widely varies across the globe with maximum occurrence of 30% in the younger population under the age of 45 years [4]. RTA's are the prime cause of head injuries responsible for 60% of such cases, with 70 lives lost every 10,000 vehicles [5].

Survivors of traumatic brain injury (TBI) often face immense hurdles that deeply impact their daily lives and independence. One of the most difficult consequences for many is skeletal muscle spasticity ,a result of upper motor neuron lesion [6] typically affecting upper limb more severely than lower limbs [7] and making daily tasks like reaching for an object or grooming more challenging. Cognitive issues add more complexities with memory lapses, problems with attention, and decision making. [8] The emotional battle is profound too, often leading to feelings of sadness and sense of isolation, further hindering their recovery. Hand function is often majorly impaired by brain injury, mostly due to muscle spasticity and its related complications, leading to impaired voluntary control [9], compromised motor function [10], and increased response time [11].

The recovery journey in TBI involves a holistic approach with a team of dedicated healthcare professionals creating a tailor-made rehabilitation programme to patient's specific needs and goals. Traditional techniques that includes slow sustained stretch and PNF are widely used in treating spasticity and has been proven quite effective. **Dafda Renuka H et al in 2021** demonstrated the effectiveness of static stretching and PNF hold-relax technique in reducing elbow flexor spasticity in stroke population [12]. In recent years, a relatively new, innovative and well tolerated tool called focal muscle vibration therapy (FMVT) has emerged as a promising addition to neurological rehabilitation. FMVT involves the vibratory stimulus applied directly on the targeted muscle at a therapeutic dose of high frequency and low amplitude, resulting in altered cortico-spinal pathway and activation of reciprocal inhibition [13]. In a study by **Tomokazu et al in 2012** indicated marked reduction in upper extremity spasticity on a direct application of vibration in post stroke patients [14].

While there are numerous studies with strong evidence supporting the effectiveness of FMV therapy in reducing spasticity among stroke survivors, there's a noticeable dearth of research exploring its potential benefits for TBI cases, which calls for further research to help refine treatment protocols and maximize functional outcomes for individuals with TBI. The current study focussed on the analysis of the benefits of FMVT on reaction timing, spasticity, motor impairments, and voluntary control of upper limb function in TBI subjects.

MATERIALS AND METHODOLOGY

Methods

The IEC approval was obtained from the Ethical committee (EC- MPT/23/PHY/013). The participants and their guardian were explained about the study purpose. A written consent for participation after explanation were obtained from the subject/guardian individually.

The study design was structured as a Randomized Controlled Trial and subjects were selected using simple random technique. The subjects were randomly divided into control and experimental group and equally assigned with 30 in each group. Patients were advised to continue their prescribed medications throughout the study. The total duration of study was 1 year and was conducted in OPD, home settings and multispecialty hospital setup in Bengaluru. Sixty subjects were recruited on the basis of selection criteria. The inclusion criteria included Both male and female population diagnosed with Traumatic Brain Injury, age of 18-40 years [15] having moderate to severe TBI with GCS score-9-12 in accordance to mayo classification for TBI severity. The subjects were required to have a minimum 10 degrees of wrist extension, thumb abduction and finger extension [16], whereas patients with Severe head injury (GCS<3), Spastic hand, Deformities of hand and Cognitive impairment (MMSE score <24) were excluded.

Outcome measures

The spasticity was assessed by Modified Ashworth Scale. The reaction time was evaluated by Ruler-drop test .Similarly Fugl-Meyer scale was used to evaluate motor hand impairment. Subject was asked to sit on the couch and using paper, ball, pencil and a small jar, the subject was assessed for motor impairment and scored based on direct observation of performance. Brunnstrom voluntary control grading was used to analyze motor performance of subject. The subject was asked to perform specific tasks and attempt to move their limbs voluntarily through various stages of recovery. The quality and extent of voluntary movement exhibited by the subject were observed and the stage of the Brunnstrom was assigned. The six component stages were used to assess the TBI subjects that described the voluntary control.

Intervention Procedure

Pre-test score measurements for spasticity, reaction timing, hand impairment and voluntary control were taken for both the groups before the commencement of the intervention, using Modified Ashworth Scale (MAS), Ruler-Drop test, Fugl Meyer Scale and Brunnstrom Voluntary Control Grading respectively.

Structured M-CIMT was administered to both control and experimental group as a baseline intervention for 10 minutes. In Structured M-CIMT, the subject was instructed to wear a constraint glove on the non-affected arm for 5 hours. The same was continued for 5 days a week for 6 weeks [17]. The caregiver was instructed to monitor the functional task relevant to everyday function at home for 10 minutes per day for a duration of 6 weeks. Four functional task were included.

Stacking blocks- subject was made to sit comfortably at a table with a variety of blocks within easy reach. The activity was started first by using bigger block and gradually smaller blocks were introduced with improvement in skill. The stacking of blocks one on top of the other was first demonstrated to make subject understand the activity better. The subject was then asked to stack the block with the affected limb and the activity was repeated multiple times. Similarly for reaching and grasping objects, subject was made to sit comfortably and a variety of objects with different shape, size and weight were kept within patient's reach. Subject was asked to reach out, touch and pick the object with the affected hand. The activity was started with large and light weighted object and slowly transitioned to smaller and heavy objects as the skills developed. Tapping tasks required subject in sitting position. A tapping board with markings was placed on the table within easy reach. Task was first demonstrated and was then asked to tap on the marked targets on the tapping board with the affected hand. The task was repeated several times. Lastly, for hand cupping/scooping task, subject was in sitting position with a bunch of coins placed on the table within easy reach. Scooping task was demonstrated and the subject was informed to use the involved hand in the same way to scoop coins from the table and transfer them to the unaffected had. The task was practiced several times.

In Control Group, Sustained stretching was given to wrist flexors with subject in supine position with hand supinated and supported by a towel under the wrist the subject's upper arm was held and elbow was gently extended in order to put a stretch on elbow flexors. The stretch was maintained for 30 seconds. It was applied for 15 minutes, thrice a week for 6 weeks.

PNF-Hold-relax was also given to the subject in supine position with hand supinated and supported by a towel under the wrist The subject's upper arm was held gently and the elbow was extended to the point of mild discomfort (initial stretch). The patient was then instructed to try to bend the elbow against resistance for about 5-10 seconds and was then instructed to relax the elbow flexors while the muscle was further stretched, increasing the range of motion. It was applied for 15 minutes, thrice a week for 6 weeks.

In Experimental Group, FMV therapy was given over the bulky part of the common wrist extensor [18] with patient in supine position with hand pronated and supported by a towel roll. The setting on muscle vibrator was set at 100 Hz. The vibrator was then placed at the muscle belly and vibratory stimulus was applied, while continuously monitoring the patient for any sign of discomfort or pain. The subject was instructed to perform deep breathing throughout the treatment period. The duration of treatment was 30minutes/session, thrice a week [19] for 6 weeks.

STATISTICAL ANALYSIS

The analysis was conducted using SPSS 21.0, a statistical programme. Both parametric and non-parametric tests were appropriately used. The graphical editors MS-WORD and SPSS were used to create the tables in the proper manner.

RESULTS

After analyzing the data, the results obtained showed improvements in both the groups for all the outcome measures. In the control group, reaction time on RDT improved from 227.10 ± 21.43 ms at baseline to 211.13 ± 17.77 ms at week 3, and 203.02 ± 13.02 ms at week 6 (Table-5). The experimental group had even better results, with reaction times decreasing from 231.90 ± 23.54 ms at baseline to 194.30 ± 8.25 ms at week 3, and 185.90 ± 9.12 ms at week 6 (Table-4). The control group's MAS score showed improvement from 3.43 ± 0.82 to 2.43 ± 0.86 at week 3, and 1.95 ± 0.81 at week 6. The experimental group had even greater improvements, with scores decreasing from 3.47 ± 0.62 to 2.27 ± 0.61 at week 3, and 1.67 ± 0.84 at week 6. The pre- and post-test results for upper limb impairment demonstrated significant differences in mean and SD. Observing the control group, it was seen that FMS scores improved from baseline levels of 6.50 ± 2.14 to 8.73 ± 1.81 at week 3 , and were further enhanced by week 6 to 8.97 ± 1.77. In the experimental group, scores were also improved from baseline level of 6.77 ± 1.83 to week 3 with 9.77 ± 1.71, with continued progress noted at week 6, reaching 10.40 ± 1.71. The control group experienced improvements in voluntary control on BVCG scale, with the gains from a baseline of 2.97 ± 0.61 to 3.63 ± 0.65 at week 3 and further to 4.43 ± 0.54 at week 6. The experimental group, however, progressed from baseline of 3.07 ± 0.64 to 4.57 ± 0.67 at week 3 and continued to show substantial improvements through week 6, reaching 5.17 ± 0.69. Comparison was done between the groups for both post-test 1 and post-test 2 and revealed that the experimental group consistently outperformed the control group indicated by significant differences favoring the experimental group ($p < 0.005$) as shown in table 6 and 7.The results strongly indicated that FMVT group significantly outperformed the control group in improving reaction timing, reducing muscle tone, and enhancing voluntary motor control and overall impairment in TBI subjects.

Table-1: **Distribution of TBI subjects in both the groups.**

| S. No. | Gender | Group | | P= 0.795 NS |
		Group-A Experimental	Group-B Control	
1	**Male**	17(56.7%)	16(53.3%)	
2	**Female**	13(43.3%)	14(46.7%)	
The above table infers the homogenous distribution of both the genders (p>0.05).				

Table-2: **Demographic data of TBI subjects in both the groups.**

| S.No. | Variable | Group-A: Experimental | | Group-B: Control | | p-value |
		Range	Mean ± SD	Range	Mean ± SD	
1	**Age in years**	21-40	32.27±5.23	21-40	30.30±5.77	t=1.382, p=0.172, NS
2	**Height(m)**	1.50-1.70	165.93±7.11	1.53-1.76	166.30±6.57	t=0.207, p=0.836, NS
3	**Weight(kg)**	45-81	64.50±11.35	53-87	67.20±10.05	t=1.040, p=0.187, NS
4	**BMI**	17.40-31.50	23.95±3.90	18.80-33.31	24.31±3.45	t=0.404, p=0.687, NS
The above table shows the demographic data of the study population indicating homogeneity (p>0.05).						

Table-3: Comparison of pre interventional scores in between the groups

S. No.	Outcome Measures	Pre interventional				p-value
		Group-A		Group-B		
		Range	Mean ± SD	Range	Mean ± SD	
1	FMS	4-10	6.77±1.83	2-9	6.50±2.14	z=0.233 p=0.816
2	MAS	2-4	3.47 ±0.62	2-4	3.43±0.82	z=0.330, p=0.742
3.	RDT(m sec)	189-271	231.90 ±23.54	191-271	227.10 ±21.43	t=0.734, p=0.466
4.	BVCG	2-4	3.07 ±0.64	2-4	2.97 ±0.61	z=0.622 p=0.534

The above table presents the comparative scores of pre-test measurement, implying the similarity of the baseline scores for the outcome measures of FMS, MAS, RDT and BVCG in both the group (p>0.005).

Table-4: Pre and post intervention values in experimental group

S.No.	Outcome measures	Group-A: Experimental						p-value
		Pre test		Post test-1		Post test-2		
		Range	Mean ±SD	Range	Mean ±SD	Range	Mean ±SD	
1	FMS	4-10	6.77±1.83	6-12	9.77 ±1.71	6-13	10.40 ±1.71	Fr=40.467, p=0.000
2	MAS	2-4	3.47 ±0.62	1-3	2.27±0.61	0-3	1.67±0.84	Fr=52.019, p=0.000
3.	RDT(m sec)	189-271	231.90 ±23.54	182-215	194.30 ±8.25	178-219	185.90 ±9.12	F=68.147, p=0.000
4.	BVCG	2-4	3.07 ±0.64	3-6	4.57±0.67	4-6	5.17±0.69	Fr=57.728, p=0.000
Pairs of **Pre with post-1:**	• FMS: z=4.398, p=0.000, S • MAS: z=4.830, p=0.000, S • RDT: t=8.819, p=0.000, S • BVCG: t=10.570, p=0.000, S			Pairs of **Post-1 with post-2:**		• FMS: z=3.827, p=0.000, S • MAS: z=3.272, p=0.001, S • RDT: t=2.396, p=0.023, S BVCG: t=4.039, p=0.000, S		
Pairs of **Pre with post-2:**	• FMS: z=4.648, p=0.000, S • MAS: z=4.823, p=0.000, S • RDT:t=9.294, p=0.000, S BVCG: t=37.696, p=0.000, S							

The above table depicts the scores obtained in the experimental group following the intervention with the pre-test scores at week 0, post-test 1 score at week 3 and post-test 2 score at week 6 indicating the significance ($p<0.005$).

Table-5: Pre and post intervention values in control group

S.No.	Outcome measures	Group-B: Control						p-value
		Pre test		Post test-1		Post test-2		
		Range	Mean ±SD	Range	Mean ±SD	Range	Mean ±SD	
1	FMS	2-9	6.50±2.14	5-13	8.73 ±1.81	6-13	8.97 ±1.77	Fr=21.394, p=0.0000
2	MAS	2-4	3.43±0.82	1-3	2.43 ±0.86	0-3	1.95 ±0.81	Fr=38.655, p=0.000
3.	RDT(m sec)	191-271	227.10 ±21.43	185-248	211.13 ±17.77	183-225	203.02 ±13.02	F =14.321, p=0.000
4.	BVCG	2-4	2.97 ±0.61	2-5	3.63±0.65	4-5	4.43±0.54	Fr=42.297, p=0.000

Pairs of **Pre with post-1:**	● FMS: z=3.112, p=0.019, S ● MAS: z=3.271, p=0.001, S ● RDT: t=6.909, p=0.000, S BVCG: t=2.511, p=0.036, S
Pairs of **Pre with post-2:**	● FMS: z=2.964, p=0.026, S ● MAS: z=2.845, p=0.031, S ● RDT: t=3.421, p=0.001, S BVCG: t=4.832, p=0.000, S
Pairs of **Post-1 with post-2:**	● FMS: z=1.913, p=0.063, NS ● MAS: z=0.699, p=0.485, NS ● RDT: t=2.215, p=0.035, S BVCG: t=3.442, p=0.001, S

The above table indicates the scores obtained in the control group following the conventional therapy with the pre-test scores at week 0, post-test 1 score at week 3 and post-test 2 score at week 6 indicating the significance ($p<0.005$).

Table-6: Comparison of Post interventional-1 scores between the groups

S.No.	Outcome Measures	Post interventional-1				p-value
		Group-A: Experimental		Group-B: Control		
		Range	Mean ± SD	Range	Mean ± SD	
1	FMS	6-12	9.77 ±1.71	5-13	8.73 ±1.81	z=2.240 p=0.033
2	MAS	1-3	2.27±0.61	1-3	2.43 ±0.86	z=2.140, p=0.012
3.	RDT(m sec)	182-215	194.30 ±8.25	185-248	211.13 ±17.77	t=2.152, p=0.031
4.	BVCG	3-6	4.57±0.67	2-5	3.63±0.65	z=4.010 p=0.000

The above table presents the comparative scores of post-test measurement 1between the groups, indicating the better effect in FMVT group (p<0.005).

Table-7: Comparison of Post intervention-2 scores between the groups

S.No.	Outcome Measures	Post interventional-2				p-value
		Experimental (n=30)		Control (n=30)		
		Range	Mean ± SD	Range	Mean ± SD	
1	FMS	6-13	10.40 ±1.71	6-13	8.97 ±1.77	z=2.656 p=0.009
2	MAS	0-3	1.67±0.84	0-3	1.95 ±0.81	z=3.087, p=0.002
3.	RDT(m sec)	178-219	185.90 ±9.12	183-225	203.02 ±13.02	t=4.847, p=0.000
4.	BVCG	4-6	5.17±0.69	4-5	4.43±0.54	z=3.941 p=0.000

The above table presents the comparative scores of post-test measurement 2 between the groups, indicating the better effect in FMVT group (p<0.005).

DISCUSSION

TBI often lead to slower response times [11], hypertonicity, and difficulties with coordination [9] and motor functions [10] leading to long-term consequences [2]. It can also affect cognitive and emotional well-being [8]. The study's objective was three-fold, aiming to explore the impact of focal muscle vibration therapy, conventional therapy, and their comparative effects on reaction timing, spasticity, hand function impairment, and voluntary control of upper limb function in TBI patients. The study included 60 participants, divided into two groups of 30 each. The assessment parameters were reaction timing, spasticity, motor hand impairment, and voluntary control, measured using the ruler-drop test (RDT), Modified Ashworth Scale (MAS), Fugl Meyer Scale (FMS), and Brunnstrom Voluntary Grading Scale (BVGS), respectively.

In the control group, reaction time improved to 203.02 ± 13.02 ms whereas in the experimental group it was further more improved to 185.90 ± 9.12 ms at post-test 2. Overall, the experimental group significantly outperformed the control group in improving reaction timing. The control group's MAS scores improved to 1.95 ± 0.81 and the experimental group showed even greater improvements, with scores decreasing to 1.67 ± 0.84 at post-test 2, showing the reduction in muscle tone in the experimental group than the control group.

The pre- and post-test results for upper limb impairment demonstrated significant differences in mean and SD. Observing the control group, it was seen that FMS scores improved to 8.97 ±1.77. However, In the experimental group, scores were also improved with continued progress noted at post-test 2, reaching 10.40 ± 1.71. A substantial difference was revealed in the comparison between groups, with significantly better outcomes shown by the experimental group.

Both groups experienced improvements in voluntary control on BVCG scale. Control group scores improved to 4.43±0.54 and experimental group, however, progressed and continued to show substantial improvements and reached to 5.17 ± 0.69 at post-test 2. Comparison was done between groups for both post-test 1 and post-test 2 and revealed that the experimental group consistently outperformed the control group indicated by significant differences favouring the experimental group ($p<0.005$).The results strongly indicated the effectiveness of FMVT in improving reaction timing, reducing spasticity, and enhancing voluntary motor control and overall impairment in TBI subjects.

The findings of this study showed improved reaction times, consistent with the research by **Antonella Macerollo et al. (2018)**, who reported significantly faster mean reaction times of 302.83 ± 52.82 ms following high-frequency peripheral vibration at 80Hz [20]. Additionally, the current study found a reduction in spasticity with focal muscle vibration (FMV), aligning with earlier work by **Casale R et al. (2014)** who demonstrated improvements in spastic biceps (P=0.0001) when using 100 Hz vibration

combined with physiotherapy to antagonist muscle [21]. This study also indicated significant improvements in hand impairment, supporting **Lian Wang et al. (2023)**, where upper limb function showed good improvement with focal vibration as measured by FMA-UE with the p score of 0.029 [22]. However, the current study finding is not in favor of **Niyousha Mortaza et al. (2019)** in upper limb function following vibration therapy (SD= -0.32) , highlighting the need for larger study population [23].

FMV is known to induce activation of muscle proprioceptors, generate adaptive synaptic changes, and lead to long-term potentiation in the CNS. This is supported by findings that show FMV's ability to generate 1a afferent impulses which alters the cortico spinal pathway influencing the inhibitory interneurons at spinal cord level [24]. Furthermore, it has been indicated that this modulation affects proprioceptive reflex circuits [25].

The significance seen in the conventional therapy group by the application of M-CIMT can be attributed to the plasticity of dendrites in the sensory motor cortex has been shown to promote the recovery of motor function by enhancing AMPA receptor-mediated synaptic transmission in the ischemic hemisphere [26] .It also promotes neurogenesis and angiogenesis by increasing the expression of factor-1α and vascular endothelial growth factor, ultimately inducing neuroprotection and functional recovery after cerebral ischemia [27].

Sustained stretching aims at promoting muscle relaxation and effective elongation. Stretch force to a muscle-tendon unit leads to change in length, thereby eliciting the stretch reflex. However reciprocal inhibition may also facilitate the stretching process by inhibiting the antagonist muscle and allowing for a deeper stretch to agonist muscle. Additionally, Golgi Tendon Organ (GTO) plays an inhibitory effect, known as autogenic inhibition that enables reflexive muscle relaxation. The traditional explanation of the underlying mechanisms of PNF stretching posits that reflexive relaxation occuring as a result of autogenic or reciprocal inhibition, resulting in decreased resistance of the muscle to stretch stimulus [28].

LIMITATION AND RECOMMENDATION

The study has several limitations that must be acknowledged. The findings from this study may not be generalizable to other neurological conditions, as the research exclusively focused on individuals with TBI. Additionally, the absence of long-term follow-up limits our understanding of the lasting effects of the intervention beyond the immediate post-intervention period. Participant adherence to the M-CIMT protocols, including home exercises, varied, which may have impacted the overall study outcomes. Despite the promising results observed in TBI subjects, it is recommended to conduct long-term follow-ups to assess the durability of the intervention's effects. Furthermore, developing strategies to improve participant adherence and expanding research to determine the intervention's applicability to a broader range of neurological conditions is necessary.

CONCLUSION

The study found that the experimental group receiving FMV therapy showed significant improvements across all outcome measures. Although the control group, which received conventional therapy, also experienced improvements, these were less pronounced. Comparatively, FMV therapy demonstrated superior efficacy in all measured outcomes. The results indicate that FMV therapy is more effective than conventional therapy in improving reaction times, reducing spasticity, enhancing hand function, and increasing voluntary control, ultimately improving the quality of life for individuals with TBI.

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CONFLICT OF INTEREST

None declared.

REFERENCES

1. Kjeldgaard A, Soendergaard PL, Wolffbrandt MM, Norup A. Predictors of caregiver burden in caregivers of individuals with traumatic or non-traumatic brain injury: A scoping review. NeuroRehabilitation. 2023;52(1):9-28.

2. Capizzi A, Woo J, Verduzco-Gutierrez M. Traumatic Brain Injury: An Overview of Epidemiology, Pathophysiology, and Medical Management. Med Clin North Am. 2020 Mar;104(2):213-238.

3. Ţolescu RŞ, Zorilă MV, Şerbănescu MS, Kamal KC, Zorilă GL, Dumitru I, Florou C, Mogoantă L, Văduva IA, Stanca L, Zăvoi RE. Severe traumatic brain injury (TBI) - a seven-year comparative study in a Department of Forensic Medicine. Rom J Morphol Embryol. 2020;61(1):95-103. doi: 10.47162/RJME.61.1.10. PMID: 32747899; PMCID: PMC7728107.

4. Dash HH, Chavali S. Management of traumatic brain injury patients. Korean J Anesthesiol. 2018 Feb;71(1):12-21.

5. Jamjoom AAB, Rhodes J, Andrews PJD, Grant SGN. The synapse in traumatic brain injury. Brain. 2021 Feb 12;144(1):18-31.

6. Enslin JMN, Rohlwink UK, Figaji A. Management of Spasticity after Traumatic Brain Injury in Children. Front Neurol. 2020 Feb 21;11:126.

7. Sunnerhagen KS, Opheim A, Alt Murphy M. Onset, time course and prediction of spasticity after stroke or traumatic brain injury. Ann Phys Rehabil Med. 2019 Nov;62(6):431-434. doi: 10.1016/j.rehab.2019.05.007.

8. Barman A, Chatterjee A, Bhide R. Cognitive Impairment and Rehabilitation Strategies After Traumatic Brain Injury. Indian J Psychol Med. 2016 May-Jun;38(3):172-81. doi: 10.4103/0253-7176.183086. PMID: 27335510; PMCID: PMC4904751.

9. Sangari S, Chen B, Grover F, Salsabili H, Sheth M, Gohil K, Hobbs S, Olson A, Eisner- Janowicz I, Anschel A, Kim K, Chen D, Kessler A, Heinemann AW, Oudega M, Kwon BK, Kirshblum S, Guest JD, Perez MA. Spasticity Predicts Motor Recovery for Patients with Subacute Motor Complete Spinal Cord Injury. Ann Neurol. 2023 Aug 22.Pellot JE, De Jesus O. Cerebral Contusion. StatPearls Publishing. 2023.

10. Flint RD, Li Y, Wang PT, Vaidya M, Barry A, Ghassemi M, Tomic G, Brkic N, Ripley D, Liu C, Kamper D, Do AH, Slutzky MW. Noninvasively recorded high-gamma signals improve synchrony of force feedback in a novel neurorehabilitation brain-machine interface for brain injury. J Neural Eng. 2022 Jun 1;19(3):10.1088/1741-2552/ac7004.

11. Norman RS, Shah MN, Turkstra LS. Reaction time and cognitive-linguistic performance in adults with mild traumatic brain injury. Brain Inj. 2019;33(9):1173-1183.

12. Dafda RH, Shah SR, Prajapati RD, Mahida AG. A Study to Compare Effect of Hold-Relax v/s Static Stretching on Elbow Flexors Muscle Spasticity in Stroke- A Comparative Study. Int J Health Sci Res. 2021 Jul;11(7).

13. Tahir S, Baig M, Rathore F, Aslam H. Focal Muscle Vibration (Review). J Pak Med Assoc. 2022;72:2126-2128. doi: 10.47391/JPMA.22-106

14. 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 Jul;44(7):637-641.

15. Adegboyega G, Zolo Y, Sebopelo LA, Dalle DU, Dada OE, Mbangtang CB, Tetinou F, Kanmounye US, Alalade AF. The Burden of Traumatic Brain Injury in Sub-Saharan Africa: A Scoping Review. World Neurosurg. 2021 Dec;156:e192-e205. doi: 10.1016/j.wneu.2021.09.021. Epub 2021 Sep 11. PMID: 34520864.

16. Bonifer N, Anderson KM. Application of Constraint-Induced Movement Therapy for an Individual With Severe Chronic Upper-Extremity Hemiplegia. Phys Ther. 2003 Apr;83(4):384-398.

17. Page SJ, Sisto SA, Levine P, McGrath RE. Efficacy of modified constraint-induced movement therapy in chronic stroke: a single-blinded randomized controlled trial. Arch Phys Med Rehabil. 2004 Jan;85(1):14-18.

18. Li W, Luo F, Xu Q, Liu A, Mo L, Li C, Ji L. Brain oscillatory activity correlates with relief of post-stroke spasticity following focal vibration. J Integr Neurosci. 2022;21(3):96.

19. 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 Feb;53(1):32-40.

20. Macerollo A, Palmer C, Foltynie T, Korlipara P, Limousin P, Edwards M, Kilner JM. High-frequency peripheral vibration decreases completion time on a number of motor tasks. Eur J Neurosci. 2018;48(2):1789-1802.

21. 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(5):495-504.

22. Wang L, Wang S, Zhang S, Dou Z, Guo T. Effectiveness and electrophysiological mechanisms of focal vibration on upper limb motor dysfunction in patients with subacute stroke: A randomized controlled trial. Brain Res. 2023;1809:148353.

23. Mortaza N, Abou-Setta AM, Zarychanski R, Loewen H, Rabbani R, Glazebrook CM. Upper limb tendon/muscle vibration in persons with subacute and chronic stroke: a systematic review and meta-analysis. Eur J Phys Rehabil Med. 2019;55(5):558-569.

24. Fattorini L, Rodio A, Pettorossi VE, Filippi GM. Is the Focal Muscle Vibration an Effective Motor Conditioning Intervention? A Systematic Review. J Funct Morphol Kinesiol. 2021 Apr 28;6(2):39.

25. Alfonsi E, Paone P, Tassorelli C, De Icco R, Moglia A, Alvisi E, Marchetta L, Fresia M, Montini A, Calabrese M, Versiglia V, Sandrini G. Acute effects of high-frequency microfocal vibratory stimulation on the H reflex of the soleus muscle. A double-blind study in healthy subjects. Funct Neurol. 2015 Oct-Dec;30(4):269-274.

26. Hu J, Li C, Hua Y, Liu P, Gao B, Wang Y, Bai Y. Constraint-induced movement therapy improves functional recovery after ischemic stroke and its impacts on synaptic plasticity in sensorimotor cortex and hippocampus. Brain Res Bull. 2020;160:8-23.

27. Li C, Zhang B, Zhu Y, Li Y, Liu P, Gao B, Tian S, Du L, Bai Y. Post-stroke Constraint-induced Movement Therapy Increases Functional Recovery, Angiogenesis, and Neurogenesis with Enhanced Expression of HIF-1α and VEGF. Curr Neurovasc Res. 2017;14(4):xxx-xxx.

28. Kisner C, Colby LA. Therapeutic Exercise: Foundations and Techniques. 7th ed. Philadelphia: F.A. Davis Company; 2017.