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RESEARCH ARTICLE

ADVANCES IN FUNCTIONAL ELECTRICAL STIMULATION FOR LOWER LIMB REHABILITATION INSTROKE: A REVIEW ON PHYSIOLOGIC AND THERAPEUTIC PERSPECTIVE

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Abstract

Stroke results in considerable impairment of lower limb (LL) function. The objective of rehabilitation is to restore pre-stroke motor skills through the promotion of neuroplasticity. Existing literature indicates that mere movement of the impacted limb does not necessarily enhance motor performance; instead, the movements should engage the patient and activate the entire neuromuscular network responsible for the intended motion. Functional Electrical Stimulation (FES) stands out among various rehabilitation strategies and is endorsed in numerous stroke rehabilitation protocols as an adjunctive therapy alongside standard care interventions. The aim of this research is to offer a thorough examination of the use and physiological rationale of FES in post-stroke rehabilitation. Many studies advocate for incorporating FES into a contemporary stroke rehabilitation regimen, complemented by activities such as cycling, treadmill exercises, and robotic interventions, to optimize recovery outcomes in poststroke rehabilitation.

Introduction:-

Stroke represents the most prevalent cause of fatality subsequent to coronary artery disease. Ramifications of a stroke encompass changes in muscle tension, weakness, spasticity, abnormal force production,postural instability, dysfunction in the upper extremities, challenges with walking, and diminished quality of life. The impediment or struggle with locomotion stands out as one of the most severe consequences of a stroke, hence the restoration of walking or gait frequently emerges as a central objective in the realm of rehabilitation. Activities linked to walking or gait entail various tasks like moving while transitioning from sitting to standing, sitting down, climbing stairs, turning, transferring (e.g., from wheelchair to bed or vice versa), walking at a brisk pace, and covering designated distances. Restrictions in walking and its associated activities are correlated with an escalation in the likelihood of falls.[1]

Numerous rehabilitation systems and physical exercises are available for individuals grappling with post-stroke or hemiplegia, which denotes weakness on one side of the body. A contemporary and extensively utilized therapeutic approach is Functional Electrical Stimulation (FES). The utilization of FES for therapeutic objectives within

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rehabilitation environments traces back to the 1960s when Liberson et al. harnessed an FES system to stimulate the peroneal nerve, rectifying foot drop by activating a foot switch. Through a singular-channel electrical stimulation apparatus, the common peroneal nerve was stimulated via a surface electrode, inducing ankle dorsiflexion throughout the swing phase of walking.[2]

FES commonly denotes the act of synchronously or sporadically pairing electrical stimulation with a functional task. A stimulation tool is employed to dispatch electrical signals to nerves, prompting muscle contractions. This form of input can bolster muscle strength and range of motion, counteracting the consequences of physical inactivity frequently observed in individuals encountering post-stroke challenges. It is frequently employed to recondition or rehabilitate muscles for improved functionality, encompassing activities such as walking or utilizing an arm for reaching. Among the lower limb issues, foot drop emerges as a prevalent complication following a stroke, potentially leading to reduced walking speed, modified step length, or even falls. By applying FES to the dorsiflexor muscles responsible for raising the foot at the appropriate timingor during the walking cycle, not only can foot clearance and safety be enhanced, but there can also be an augmentation in muscular strength and ankle joint flexibility.[3]

Therapeutic Vs. Prosthetic effect of Functional electrical stimulation (FES)

The two principal applications of Functional Electrical Stimulation (FES) entail the substitution of function, such as acting as an orthotic device and the retraining of function, exemplified by its therapeutic use. When individuals who have experienced a stroke utilize a FES motor relearning system to rehabilitate lower limb movements and activities, the primary objective is focused on training to ensure sustained enhancement in the functional utilization of the hemiparetic limb even during periods of non-use. The enduring enhancement in lower limb function or mobility subsequent to undergoing FES training or utilizing the device is identified as a therapeutic outcome. For individuals in the chronic phase of stroke with depleted motor relearning options, FES can serve as a neuroprosthesis. The central goal in this context is to empower patients to perform daily functional tasks using the affected lower limb or to walk while incorporating the device into their routine activities. The enhanced functionality observed while employing an FES device is denoted as a neuroprosthetic or orthotic benefit. An evaluation of the existing literature regarding the advancement in walking abilities among stroke patients with foot drop when employing peroneus stimulation indicates a favorable orthotic impact of Functional Electrical Stimulation on walking speed.[4,5]

Physiologic effect of FES

It has been found that therapies that temporally link motor output and sensory feedback from the affected limb may facilitate neurophysiologic changes leading to motor recovery.The peripheral mechanism of FES involves enhancing the paralyzed limbs muscle flexibility, strength, range of motion, and reducing spasticity.[9]FES can help restore muscle strength, particularly in the dorsiflexors and hip abductors, aiding in weight-bearing, postural support, and balance improvement.Several studies indicate that the rehabilitation potential of Functional electrical stimulation can range from the modulation of motor function in various levels of motor recovery of individuals to reduction in impairment severity .[7,8]

Neuroplasticity and FES

Functional electrical stimulation can improve neuroplasticity by increase in synaptic efficacy within existing neural circuits or formation of new synapses. FES assisted movement causes cortical reorganization by acting as proprioceptive inputs to the brain and reinforcing network connection patterns through the creation of new synapses.[10]FES maximizes the motor output (peripheral efferent activation) and corresponding muscle and joint proprioceptive feedback (afferent activation) that are tightly coupled and coordinated with movement by FES.TheHebbian mechanisms related to activity dependent cortical reorganization suggest that rehabilitation therapies that repeatedly generate synchronous presynaptic and postsynaptic neural activity along motor and sensory pathways might facilitate synaptic remodeling, leading to neural reorganization and motor recovery.[6]

Therapeutic applications of Functional Electrical Stimulation (FES)

The utilization of FES has been endorsed by the Clinical Guidelines for Stroke Management and Guidelines for Adult Stroke Rehabilitation and Recovery as an adjunctive intervention alongside standard care modalities.[11, 12]

Various Systematic reviews and Meta-analysis, as demonstrated in table 1, have indicated that the incorporation of FES into a conventional rehabilitation regimen yields favorable therapeutic outcomes concerning enhancements in

tone, gait recovery, motor function, energy expenditure, and functional capacity among stroke patients. These reviews have highlighted the beneficial impact of FES on lower limb motor impairments and functional results. [13-19]

A substantial body of literature substantiates the efficacy of FES in ameliorating lower limb motor control through a variety of outcome measures such as Functional Ambulation Category, Berg balance test, 10-m walk test, timed-up-and-go (TUG) test, Fugl-Meyer lower extremity, Motricity Index, Barthel index, and Six-minute walk test.[20-32]

Few Studies found AFOs to have positive combined-orthotic effects on walking that are equivalent to FES for foot-drop caused by stroke.[5,33] Also FES is effective in improving the temporal-spatial gait and activities of daily living in hemiplegic stroke patients.[34]

TABLE 1 : SYSTEMATIC REVIEWS AND METAANALYSIS ON EFFECTS OF FES FOR LOWERLIMB REHABILITATION FOR POST STROKE RECOVERY

Authors	Endpoints	Findings
Glanz et al, 1996[14]	Muscle strength/Torque	Positive therapeutic effects found on various outcome measures
Robbins SM et al, 2006[17]	Gait speed/ Walking	
Pereira S et al, 2012[16]	Gait speed/ Walking	
Sabut S.K et al, 2013 [40]	gait, motor function,energy expenditure	
Stein C et al, 2015[41]	Spasticity/Range of Motion	
Howlett O et al, 2015[13]	Gait speed	
Prenton S et al, 2016[5]	Gait speed/Orthotic effect	Less orthotic effect
Francisco L et al, 2016[42]	Quality of life, motor abilities and gait	Positive therapeutic effect
Mahmoudi Z et al,2021[18]	Balance /BBS/ TUG	
Kang et al, 2021[33]	Implantable FES/ Gait performance	Superior gait parameters
Fang Y et al,2023[19]	Motor, Balance and ADL	Superior to other electrical stimulation

Various methods of application

In hemiplegia multichannel stimulation systems have been investigated for therapeutic effects. Surface electrodes are used with a 6-channel surface system to activate ankle dorsiflexion , plantar flexion, knee flexion, knee extension, hip flexion and extension. However, as the number of electrodes increases, surface systems become increasingly difficult to implement due to difficulty of donning and doffing of multiple electrodes, pain of stimulation, difficulty in electrode placement and muscle contractions. Therefore, multichannel percutaneous systems have also been explored for motor relearning. [23,33, 35]

Hybrid FES

New FES techniques for lower limb stroke rehabilitation continue to be developed, especially those that use sensors to trigger stimulation when patients achieve some minimum volitional movement. EMG-controlled Functional Electrical Stimulation (FES) induces greater muscle contraction by electrical stimulation that is in proportion to voluntary integrated EMG signals. There is a growing trend toward combining FES with other emerging therapeutic strategies. Examples include combining FES with Brain Cortical Interface (BCI), repetitive trans cranial magnetic stimulation (rTMS), constraint induced movement therapy (CIMT) robot-assisted movement therapy, motor imagery, bilateral movement training, virtual reality games, trans cranial direct current stimulation (tDCS), and body-weight-supported treadmill training(BWSTT).[36,39]

Discussion:-

It was previously believed that the central nervous system, had no ability to regenerate or change, So compensatory strategies were focus of stroke rehabilitation. However, with the increasing awareness that brain plasticity, neural regeneration, and rehabilitation therapy can promote recovery, the focus has shifted toward treatments that maximize neurological recovery. So now -a -day's rehabilitation therapy using a restorative approach is the main focus to reduce impairments and improve functional activity.

Therapeutic FES assists functional tasks in a synergic way and encourages user effort. In addition, recent evidence supports the assumption that BCI-based FES could improve motor recovery after stroke. Also, evidence are there for improving lower extremity motor function in patients with early stroke through combining magnetic resonance diffusion tensor imaging (DTI) technology and functional electrical stimulation (FES) based on human walking patterns.[37] Most trials to date have stroke patients in the subacute and chronic stage of stroke recovery. [38] Studies now are examining the effects of FES therapy in early recovery stages. In addition, current research is focusing on FEST dosage parameters to improve the trial methodology.

Conclusion:-

Evidences from the literature suggest that FES is beneficial in improving lower limb motor impairments and functional activity performance after stroke. Better understanding of both neurophysiology and the clinical applications of FES therapy would increase its therapeutic effects and become a component of routine clinical practice in addition to conventional modalities in post stroke rehabilitation.

References:-

1. Li S, Francisco GE, Zhou P. Post-stroke Hemiplegic Gait: New Perspective and Insights. Front Physiol. 2018 Aug 2;9:1021.
2. Taylor MJ, Schils S, Ruys AJ. Home FES: An Exploratory Review. Eur J TranslMyol. 2019 Nov 12;29(4):8285. doi: 10.4081/ejtm.2019.8285.
3. Popović, D.B.; Popović, M.B. Advances in the use of electrical stimulation for the recovery of motor function. Prog. Brain Res. 2011, 194, 215–225.
4. Rushton, D. Functional Electrical Stimulation and rehabilitation—An hypothesis. Med. Eng. Phys. 2003, 25, 75–78
5. Sarah Prenton, Kristen L. Hollands, Laurence P. J. Kenney, functional electrical stimulation versus ankle foot orthoses for foot-drop: a meta-analysis of orthotic effects;JRehabil Med 2016; 48: 646–656
6. Seitz, R.J.; Matyas, T.A.; Carey, L.M. Neural Plasticity as a Basis for Motor Learning and Neurorehabilitation. Brain Impair. 2008, 9, 103–113
7. Nudo, R.J. Recovery after brain injury: Mechanisms and principles. Front. Hum. eurosci. 2013, 7, 887.
8. Arya, K.N.; Pandian, S.; Verma, R.; Garg, R. Movement therapy induced neural reorganization and motor recovery in stroke: A review. J. Bodyw. Mov. Ther. 2011, 15, 528–537.
9. Barss, T.; Ainsley, E.N.; Claveria-Gonzalez, F.C.; Luu, M.J.; Miller, D.J.; Wiest, M.J.; Collins, D.F. Utilizing Physiological Principles of Motor Unit Recruitment to Reduce Fatigability of Electrically-Evoked Contractions: A Narrative Review. Arch. Phys. Med. Rehabil. 2018, 99, 779–791
10. Shin HE, Kim M, Lee D, Jang JY, Soh Y, Yun DH, et al ,Therapeutic Effects of Functional Electrical Stimulation on Physical Performance and Muscle Strength in Post-stroke Older Adults: A Review. Ann Geriatr Med Res. 2022 Mar;26(1):16-24. doi: 10.4235/agmr.22.0006.
11. Winstein, C.J.; Stein, J.; Arena, R.; Bates, B.; Cherney, L.R.; Cramer et al. Guidelines for Adult Stroke Rehabilitation and Recovery: A Guideline for Healthcare Professionals from the American Heart Association/American Stroke Association. Stroke 2016, 47, e98–e169
12. Gittler, M.; Davis, A.M. Guidelines for Adult Stroke Rehabilitation and Recovery. JAMA J. Am. Med. Assoc. 2018, 319, 820–821.
13. Howlett, O.A.; Lannin, N.; Ada, L.; McKinstry, C. Functional Electrical Stimulation Improves Activity After Stroke: A Systematic Review with Meta-Analysis. Arch. Phys. Med. Rehabil. 2015, 96, 934–943.
14. Glanz M, Klawansky S, Stason W, Berkey C, Chalmers T C. Functional electrostimulation in poststroke rehabilitation: a meta-analysis of the randomized controlled trials. Archives of Physical Medicine and Rehabilitation 1996; 77(6): 549-553
15. Roche A, Laighin G, Coote S. Surface-applied functional electrical stimulation for orthotic and therapeutic treatment of drop-foot after stroke: a systematic review. Physical Therapy Reviews 2009; 14(2): 63-80
16. Shelialah Pereira, Swati Mehta, Amanda McIntyre, Liane Lobo , Robert W. Teasell, Functional Electrical Stimulation for Improving Gait in Persons With Chronic Stroke;Top Stroke Rehabil 2012;19(6):491–498
17. Robbins SM, Houghton PE, Woodbury MG, Brown JL. The therapeutic effect of functional and transcutaneous electric stimulation on improving gait speed in stroke patients: a meta-analysis. Arch Phys Med Rehabil2006;87:853-9

18. Mahmoudi Z, Mohammadi R, Sadeghi T, Kalbasi G. The Effects of Electrical Stimulation of Lower Extremity Muscles on Balance in Stroke Patients: A Systematic Review of Literatures. J Stroke Cerebrovasc Dis. 2021 Aug;30(8)
19. Fang Y, Li J, Liu S, Wang Y, Li J, Yang D, Wang Q. Optimization of electrical stimulation for the treatment of lower limb dysfunction after stroke: A systematic review and Bayesian network meta-analysis of randomized controlled trials. PLoS One. 2023 May 11;18(5).
20. Lee, J. B., Kim, S. B., Lee, K. W., Lee, J. H., Park, J. G., & Lee, S. J. (2019). Combined therapy with functional electrical stimulation and standing frame in stroke patients. Annals of Rehabilitation Medicine, 43(1), 96-105.
21. Zheng, X., Chen, D., Yan, T., Jin, D., Zhuang, Z., Tan, Z., & Wu, W. (2018). A randomized clinical trial of a functional electrical stimulation mimic to gait promotes motor recovery and brain remodeling in acute stroke. Behavioural Neurology, 2018, 1-10.
22. You, G., Liang, H., & Yan, T. (2014). Functional electrical stimulation early after stroke improves lower limb motor function and ability in activities of daily living. NeuroRehabilitation, 35(3), 381-389.
23. Ferrante, S., Chia Bejarano, N., Ambrosini, E., Nardone, A., Turcato, A. M., Monticone, M., Pedrocchi, A. (2016). A personalized multi-channel FES controller based on muscle synergies to support gait rehabilitation after stroke. Frontiers in Neuroscience, 10, 425.
24. Thibaut, A., Moissenet, F., Di Perri, C., Schreiber, C., Remacle, A., Kolanowski, et al (2017). Brain plasticity after implanted peroneal nerve electrical stimulation to improve gait in chronic stroke patients: Two case reports. NeuroRehabilitation, 40(2), 251–258.
25. Tan, Z., Liu, H., Yan, T., Jin, D., He, X., Zheng, X et al (2014). The effectiveness of functional electrical stimulation based on a normal gait pattern on subjects with early stroke: A randomized controlled trial. BioMed Research International, 2014, 1–9.
26. Lee, J.B., Kim, S.B., Lee, K.W., Lee, J.H., Park, J.G. and Lee, S.J., 2019. Combined therapy with functional electrical stimulation and standing frame in stroke patients. Annals of rehabilitation medicine, 43(1), pp.96-105.
27. Moon S-H, Choi J-H, Park S-E. The effects of functional electrical stimulation on muscle tone and stiffness of stroke patients. J PhysTherSci 2017;29:238-241.
28. Lee JB, Kim SB, Lee KW, Lee JH, Park JG, Lee SJ. Combined therapy with functional electrical stimulation and standing frame in stroke patients. Annals of rehabilitation medicine. 2019 Feb 28;43(1):96-105.
29. Jung J. The effects of functional electrical stimulation applied to the gluteus medius and tibialis anterior on stair climbing ability in persons with stroke. Physical therapy rehabilitation science. 2018;7(3):134-8.
30. Araki S, Kawada M, Miyazaki T, Nakai Y, Takeshita Y, Matsuzawa Y, Yamaguchi Y, Ohwatashi A, Tojo R, Nakamura T, Nakatsuji S. Effect of Functional Electrical Stimulation of the Gluteus Medius during Gait in Patients following a Stroke. BioMed Research International. 2020 Nov 19;2020.
31. Allen JL, Ting LH, Kesar TM. Gait rehabilitation using functional electrical stimulation induces changes in ankle muscle coordination in stroke survivors: a preliminary study. Frontiers in neurology. 2018 Dec 20;9:1127.
32. Phongamwong C, Rowe P, Chase K, Kerr A, Millar L. Treadmill training augmented with real-time visualisation feedback and function electrical stimulation for gait rehabilitation after stroke: a feasibility study. BMC Biomedical Engineering. 2019 Dec;1(1):1-7.
33. Kang GE, Frederick R, Nunley B, Lavery L, Dhaher Y, Najafi B, Cogan S. The Effect of Implanted Functional Electrical Stimulation on Gait Performance in Stroke Survivors: A Systematic Review. Sensors (Basel). 2021 Dec 13;21(24):8323. doi: 10.3390/s21248323.
34. Oh D, Yoo K. Effects of Functional Electrical Stimulation (FES) on the Temporal-spatial Gait Parameters and Activities of Daily Living in Hemiplegic Stroke Patients. KSPM 2021;16:37-44.
35. Van Bloemendaal, M., Bus, S. A., Nollet, F., Geurts, A. C., & Beelen, A. (2021). Feasibility and preliminary efficacy of gait training assisted by Multichannel Functional Electrical Stimulation in early stroke rehabilitation: A pilot randomized controlled trial. Neurorehabilitation and Neural Repair, 35(2), 131-144.
36. Zhang, X., Gu, T., Liu, X., Han, P., Lv, H., Wang, Y., & Xiao, P. (2021). The effect of transcranial direct current stimulation and functional electrical stimulation on the lower limb function of stroke patients. Frontiers in Neuroscience, 15. doi:10.3389/fnins.2021.685931
37. Chen D, Yan T, Li G, Li F, Liang Q. [Functional electrical stimulation based on a working pattern influences function of lower extremity in subjects with early stroke and effects on diffusion tensor imaging: a randomized controlled trial]. Zhonghua Yi XueZaZhi. 2014 Oct 14;94(37):2886-92.
38. Kim YW. Update on Stroke Rehabilitation in Motor Impairment. Brain Neurorehabil. 2022 Jul 20;15(2):e12. doi: 10.12786

39. Díaz, I., Gil, J. J., & Sánchez, E. (2011). Lower-limb robotic rehabilitation: Literature review and challenges. Journal of Robotics, 2011, 1-11.
40. Sabut SK, Bhattacharya SD, Manjunatha M. Functional electrical stimulation on improving foot drop gait in poststroke rehabilitation: a review of its technology and clinical efficacy. Crit Rev Biomed Eng. 2013;41(2):149-60.
41. Stein C, Fritsch CG, Robinson C, Sbruzzi G, Plentz RD. Effects of Electrical Stimulation in Spastic Muscles After Stroke: Systematic Review and Meta-Analysis of Randomized Controlled Trials. Stroke. 2015 Aug;46(8):2197-205.
42. Romera-De Francisco L, Jimenez-Del Barrio S. Effectiveness of functional electrical stimulation in stroke patients: a systematic review. Rev Neurol. 2016 Aug 1;63(3):109-18.