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Synergetic Innovation of Cranial Nerves and Biomedical Engineering: Promoting the Frontier of Brain Science

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Abstract: It has been suggested that the field of biomedical engineering has been instrumental in creating new therapeutic modalities in rehabilitation of neurological disorders as well as motor dysfunction. Much of this can be attributed to advancements in the scientific research of the cranial nerves. This paper has an objective which is to combine all the efforts including and not limited to the use of electrical stimulation, imaging technique and various cranial imaging techniques in the repair of the cranial nerves. The narrative of this article will look at the synergistic effects of the use of such technology including how it may enhance certain working parameters in the patient through electrical stimulation, autologous nerve and bio-mimic engineered/derived recell scaffolds and Brain-Computer interfaces. Multidisciplinary approaches other than comprehensive examination and analysis of peer reviewed articles, clinical experiments, tests etc. which were relevant to seizures were also used for seaching of the topics of study. Qualitative and Quantitative methods were deployed to evaluate the outcome of applying electrical stimuli, BCIs as well as tissue-engineered scaffolds in the improvement of patient performances. The results consequence of the studies state that for instance electrical stimulation of cranial nerves can improve and restore cognitive abilities and also can be used for treatment of the neurologic disorders that are in existence. Neuromodulation is one of the applications that has some effects of improvement in the brain of the individual and direct treatment for disorders of neurology. There are thus many therapies that are directed for treatment of neurologicTissue engineering methods showed an effective strategy for restoring function in motor cranial nerves; however, the challenges of therapy are due to problems such as misdirection of reinnervation. Brain computer interfaces on the other hand offer a solution for the restoration of lost motor function with significant improvements. It is possible to achieve an increase in the recovery rate by up to 25% using the techniques of motor imagery and neurofeedback. Although the said positive attributes are present in reality, the document credences that more work still needs to be done in the investigation of new technologies, free from the bias on these existing technologies.

Keywords: Cranial Nerves; Biomedical Engineering; Electrical Stimulation; Brain-Computer Interface (BCI); Motor Disorders; Tissue Engineering; Neurorehabilitation.

1. Introduction

Recently, the problems of cranial nerves and their techniques are on the rise. The fields of biomedical engineering and cranial research, separately limited in their potential to offer findings that further the advancements made in efforts to understand and control the brain, promise very favorable opportunities when applied together. Such an interdisciplinary effort improved not only the understanding of the working of the cranial nerves, but also showed how they could be made to work better at both ends of the health-disease scale. For example, the use of electrical stimulation to functionalize the cranial nerves is becoming an important subject for enhancing cognition, and restoring or ameliorating certain brain diseases. The use of BCIs, which is the combining of electrical interfaces and BCI machines, along with neurotherapy, has also picked up significantly in the treatment of motor impairment and the promotion of neurorehabilitation. Luo (2024) gives a picture of a new research how BCIs are connected with the improvement of motor disorders and explains the relations even further using the examples by neuromarketing (Luo, 2024). This combination of science and technology changes the way how patients with impairments can do some physical activities and therapies.

Nanotechnology shows yet another example of a cross-disciplinary approach which works within the scope of biomedical engineering – that of modifying the brain structure. They assert how nanotechnology has allowed for the identification of biomarkers in neuro-oncology, facilitating the control of brain tumors through advanced genomic and proteomic techniques within an enlightening discussion on inter disciplinary research (Ganau et al., 2018).

However, despite the achievements in the fields of cranial nerve and biomedical engineering research, there remain significant challenges, which are particularly related to the development of neuroregenerative and neurorehabilitation techniques in case of various diseases or traumas. The damage to cranial nerves, especially motor cranial nerves, due to their physiology's limitations generally does not heal completely due to the processes of regeneration and where present, aberrant reinnervation. On the other hand, Xie et al. (2020) demonstrate that there are still problems in the course of restoration of functional reconstruction of motor cranial nerves, even when the existing reconstruction techniques are accessible, and note the insufficiencies of the current technologies in the respect that full recovery of motor function is yet a mirage (Xie et al., 2020).

Equally complicating the situation is the existence of concerns with regard to the ability of developing technologies that will effectively comport biological neural systems with engineered solutions. Whilst interesting devices such as the 'Galeno' neurosurgery system have shown some potential in treating such complex brain conditions as herniation and cases of stroke quite effectively, redressing the challenges associated with integration of these remaining technologies required trepidation (Piscitelli, 2024).

Additionally, as Lei (2023) notes, while BCIs have shown effectiveness in enhancing motor imagery for rehabilitation, issues such as the constraints in signal acquisition and the integration of metaverse technology to simulate real-world situations are yet to be fully explored (Lei, 2023). The challenge is not only technical but also associated with patient compliance as well as the burden of implementing such advanced strategies.

Therefore, the main contribution of the present work is the potential of combined research in cranial recording and biomedical equipment for the development of neurosciences. The purpose of the study is, therefore, to discuss the changes occurring with the integration of the fields of interests and their use to bring about changes in the forms and methods of treatment and diagnostic interventions in the field of neural restoration, rehabilitation and BCI.

The convergence of the science of cranial nerve research with technology of bio-medical or product is expected to inject the field of neural regeneration with the vigor for a new higher dimension of restoration of neural structures. For example, achievements of tissue engineering in the context of specific conditions of cranial nerves and their anatomy will be able to conceptualize more effective strategies of reconstruction and regeneration in the setting of nerve injury. As Xie et al. (2020) put in contrary to this, enhancing such rehabilitation approaches could go a long way in reducing the permanent disabilities often associated with motor injury to cranial nerves (Xie et al., 2020).

Concerning treatment, the study proposes a modification of current strategies, while utilizing BCI technology and neurofeedback. Lei (2023) suggests that such methods as BCIs help recover motor abilities in patients with muscular diseases, and enhance the capability to perform motor imagery in the frame of virtig (or virtual) rehabilitation – i.e., using bcis to create situations wherein patients are able to virtually walk and perform other movements in a video game (Lei, 2023). These go with the expansion that new approaches applied in the treatment of motor disorders might be more effective, at the time they also offer patients with impaired mobility better and custom made rehabilitation programmes.

Again, the study terms abovementioned breakthrough as moderate acknowledging patient related complexities such as mastering of BCIs for medical RM, managing work and social status. As the potential of brain computer interaction has greatly improved with conventional neuroprosthetics such as BCIs, and in time will be even better with such technologies as BCIs, a focus has been placed on investigational devices aimed at addressing the memory of subjects with brain damage and information processing tasks.

On a totally different note, Daniel (2021) explains how some of the emerging technologies that allow human beings to make use of their brains and senses in new ways such as brain implants and sensory enhancements have begun to challenge the age-old concept of 'human self' and human sensations(Daniel, 2021).

The merit of this research, however, does not stem solely from inducing inferences meant for practical utility. By establishing the synergy between cranial nerve research and biomedical engineering, scientists and clinicians can promote the development of more efficient diagnostics, as well as treatments and rehabilitation of patients affected by neurologic conditions, thus improving their quality of life.

2. Methods

Study Design

This research adopts a multidisciplinary approach to investigate the intersection of cranial nerve innovation and biomedical engineering. The study focuses on the integration of methods such as electrical stimulation, tissue engineering, and brain-computer interfaces (BCIs). These methods are selected for their relevance in advancing neural regeneration, cranial nerve repair, and neurorehabilitation. By employing this combination of approaches, the study aims to explore how synergetic innovations can be used to promote the treatment related applications within brain science and neurorobotics.

For example, recent advancements in the field of facial nerve regeneration report the combined application of nerve stimulation and biomaterials for improvement of function in a paralyzed face. Langhals et al. (2014) presents another research, which is based on tissue engineering strategies in combination with surgical techniques which aim at functional restoration of injured nerves, emphasizing the importance of an interdisciplinary approaches (Langhals et al., 2014). Similarly, the development of tissue-engineering has already demonstrated efficacy in assisting spinal nerve regeneration through large degree tissues engineering as well as surface engineering of spinal cord channels.

Several technological and medical studies that will be relevant to this period are applicable to brain-computer interfaces. The progress achieved in BCI is particularly invaluable for those suffering from motor disabilities, as it enhances motor recovery. So too is the realization that BCIs in rehabilitation improve medical conditions for example patients with nervous system lesions. It is also about the technologies or the apprenticeship the article is concentrating on and refers to motor imagery training, such as motor loss treatment via motor activities performed in virtual reality (VR) or through other neurofeedback methods using brain–computer interfaces. Lei (2023).

Participant Selection

For this research, the selection of the population will be like impure articles, regional examinations, and trials, which represent cases of electrical stimulation, the methods of treatment using synthetic tissues and BCI. The criteria of incorporation are directed at where they may potentially be useful in a certain medical condition, including in the treatment of damaged cranial nerves, neural recovery and improvement, and in patients with disabilities and neurorehabilitation.

Studies focusing on the reconstruction of cranial nerves and their neuromuscular junctions are particularly interesting, how they or will they but for now forcus on restoring them as with them so much of motor function is lost. Steps have been taken to identify which facts have been attained in progresses in cranial motor nerve repair including work done by Xie and lung in the year 2018 where the authors capture reviews such as nerve gap filling: neurografth, immunomodulator, and electrical stimulation for the process of regeneration (Haley et al., 2019). These strategies are necessary in the field of nerve repair problems and motor deficits because nerve regeneration is often compromised by weak axonal growth and inappropriate muscle reinnervation.

Excellent new surgical techniques addressing injuries to the nerves are some of the things that scrutinitized in the selection of the research. Possibly, one of the advanced surgeries Mackinnon (2018) talks aboutinvolves nerve surgeries which could be peripheral personal nerve transplants and or conversion of a nerve canal into a bioengineered one–no end to the columns of text and again biomedical engineering receives a more age unlike the present surgeries (Mackinnon, 2018).

Data collection process

Process of data collection involves the reviewing of academic articles, clinical and experimental data offered by the random case or controlled clinical trials and experimental studies involving the study of cranial nerves and biomedical enginering. These data are equally significant when it comes to identifying the intersections and points of strength enhancement between the processes of neural engineering and rehabilitation that increases clinical effects.

One of the main sources of data comprises systematic reviews and meta-analyses addressing the issue of nerve regeneration. For example, Huang et al. (2006) develop biodegradable polymer substrates facilitating axonal sprouting and nerve healing. These substrates function as support deflecting certain growth of nerves, especially regarding large desert in repair, where healing without help cannot occur (Huang & Huang, 2006).

In addition, data is employed from experimental studies on bioelectric interfaces to evaluate their impact on restoration of motor and neural functioning. Grafts utilizing the bioelectric connectors necessitate the application of the receptors which are normally exposed to the interface and while chronic implanting of the same, gliosis and scarring occur as a challenge to the effect for the use of the prosthetic devices. In addition to this, the impact of tissue engineering and neurobiology on the improvement of these prosthetic devices in the long run is captured in the works of Leach and Pisio (2009) through a study detailing the solutions engineering presents to bruising challenges (Leach & Pisioukkarose, 2009).

There is also collection of information from the conducted clinical studies that seek to explore the potential of BCIs in neuro rehabilitation. Lei (2023) mentions the success factors of the imaginary activity enhancement in physical health and functional abilities especially where there is a motor deficit. In what regards this data the practical importance of BCI in neurorehabilitation is provided in the form of rehabilitation programs, demonstrating on how the patients improved skills through the use of virtual world and bio practices which is a japanesse game (Lei, 2023).

In the last but one section will be capturing data from experimental studies on 3D bioprinting and tissue engineering to determine how these methodologies can aid with restoration of the nervous system. An article written by Abdolmaleki et al. (2023) shows the usage of nozzle-free 3D-printed implants for nerve restoration which avers that such restoration is not limited to the central nervous system but also to the peripheral nervous system (Abdolmaleki et al, 2023).

Data Analysis

This study applies both qualitative and quantitative data analysis methods to examine the undisturbed work between biomedical engineering and cerebral nerve surgeries. The qualitative research puts emphasis on the interactions, if any, of biomedical advances in tissue engineering or the use of thoracic reading brain (BCI) and techniques for nerve repair and plastic surgery. The scope of this review will involve going through various published studies bearing in mind the strategies employed to address intersection of these domains and possibly get an insight into the management of such conditions in the future.

For example, such studies that utilize magnetic resonance imaging (MRI) for cranial nerve imaging also provide a rich study of the anatomy of cranial nerves suitable for normal and clinical assessment; the said anatomy is detailed, giving an accurate overview of the nerve to the structure and the surface being considered in the most difficult areas of clinical practice' (Casselman et al., 2008, p. 520). Dumas et al. 2002 emphasize the need for tailor-made MR studies as these are crucial in understanding the anatomy of cranial nerves and the related conditions and allow the advance in diagnosis and surgery due to use of the fast emerging imaging modalities for diagnostic and surgical interventions (Dumas et al. 2002).

Qualitative data analysis is conducted through counting, ranking, and evaluating relationships of such designed features as part of data gathered and included in clinical trials and experimental studies. Use of finite element analysis (FEA) for mechanical evaluation of cranial nerves is a constructive quantitative tool. Further, examples would also be found in the section of the book prepared by Wysocki and Doyle (2023) which dealt specifically with the evaluation of material properties in osteological structures (Wysocki & Doyle, 2023).

Also, such sophisticated data analysis methods as artificial neural networks (ANNs) are now increasingly used in biomedical research to facilitate the analysis of complex datasets. It can be noted that there is a troublesome application of ANNs that has been described to acquire the study by Narkevich which is an analysis of the vast collection of biomedical records (Narkevich, 2021). In this context, the eye of development remains on the use of both quality and quantity analytical techniques towards the exclusive about forwarded energy mechanical techniques. The overall aim of this study is to understand how the advancement of biomedical engineering is enabling the growth of cranial nerve research, more in terms of increased diagnostic and rehabilitation procedures and surgical intervention improvement leading to better treatment outcomes tonight.

3. Outcomes

Discoveries and Evidence Considered

Applying an electrical current to the nerves inside our head can be useful in the enhancement of cognitive functions, and it is possible to provide site-specific therapies for certain neurological diseases. It is feasible and practical to simulate certain cranial nerve pathways in order to optimize cerebration as optics in short runs among the patients with cognitive insufficiency, depression and other neurological conditions. Adair et al. (2020) determined that the stimulation of the trigeminal nerve and other cranial nerves can be of help in the patient's enhancement of the aspects of the cognitive system due to the targeting of specific structures present in various brain areas of memory and executive function. Such an innovative approach allows treating Alzheimer's and epilepsy in patients as well without surgery such as the new technique of stimulation mentioned by Adair et al. (2020)

Shi et al. (2000) in another work examined the combined application of electrical stimulation and pharmacological iontophoresis to expedite the regeneration of a facial nerve that has been injured traumatically. The results were convincing such that more myelin repair and growth of axons is noticeable indicating that the use of MCS (Shi et al., 2000) is beneficial in nerve generation. However, reaching high intensity of electric stimulation may be unacceptable distraction, on the one hand, due to skin and tissue damage issues (Emmanuel, 2022).

Moreover, the application of tissue engineering trends exhibits noticeable achievements in stimulating motor cranial nerve regeneration. Xie et al. (2020) reviewed several constructs that are aimed at improving motor nerve repair with tissue engineering including the involvement of biomaterials and scaffolds to promote axonal elongation. However, motor recovery paradigms still face serious reinnervation issues which stem from achiing that engages the target muscles and thus assist in functional restoration (Xie et al., 2020).

Recent developments in 3D bioprinting have led to new approaches for eliminating the issues of nerve degeneration. For instance, Abdolmaleki et al. (2023) put into practice the application of scaffolds that have proper dimensions due to being three-dimensional printed in cases when there was a need to repair nerves in the central and peripheral nervous systems. There scaffolds get the nerve tissue to be regenerated in a success oriented way despite being limited in overcoming the limitations of the traditional nerve graf (Abdolmaleki et al., 2023).

With the development of swift information technologies for communication signals, modern neurophysiologists also succeeded in constructing machines named brain-computer interfaces. Brain-Computer Interfaces (BCIs) restore lost motor functions in patients suffering from various motor disorders. The BCIs help the patients to issue a command and move, reach, or grab an object and break through the frontiers with a thought as a source of energy. Out of the BCIs investigated Lei (2023) has shown that, using topographic electrode montages for motor imagery tasks and implementing brain-computer interfaces, recovery of motor function has been markedly improved in stroke patients. Being able to have an interactive session that elaborates motor ability with the equipment is the essence of neurorehabilitation, particularly in quadriplegia and age-related illnesses (Lei et al., 2023).

Furthermore, Herring et al. (2023) Publicized how the Restorative capabilities of neural interfaces they used Retinal Implants in terms of optical and cochlear implants for tetraplegic patients consistent with motor and sensory impairments. The only untapped combination of neural interfaces is marginal neural stimulation, as that may provide appropriate patient care in the rehabilitation of patients with severe motor involvement (Herring et al., 2023).

Multivariate meta-analysis results point to the effectiveness of the new approaches in the practice of the given field. This is because, in the case of Neurofeedback after surgical removal of MR, as well as neurofeedback in children with motor disorders, there has been an increased number of the BCIs. Lei (2023) truthfully stated that the patients whose physiotherapy included the course of upper limbs recovery with simultaneous operation of a computerized hand expander experienced hand recover of some 25% more as compared to the patients that were treated in the control group i.e. using only traditional therapy. The significant marked improvement in the recovery activity fosters the idea of applying BCIs in filed the of neurorehabilitation (Lei et al., 2023).

It has also been shown that the application of electrical stimulation can lead to fast healing of nerves after facial nerve damage. Conversely, Shi et al. (2000) found that a combined use of electrical stimulation and iontophoresis, led to enhanced axon extension over that of myelination which went as fast as that traditional therapy would have allowed.

However, the risk of damage to the tissues at high intensities of stimulation has always been an issue, which means that the optimization of the stimulation protocols should be further worked on (Shi et al., 2000).

In summary, the results of these studies demonstrate interdisciplinary application of cranial nerve regeneration studies and innovations in the field of biomedical engineering to handle optimization challenges of neural regeneration and neurorehabilitative care.

4. Discussion

Neuromedicine and biomedical technology's integration was proved significant for both preventive and remedial medical approaches. This alternative technique was also observed within the same discipline, within that framework the utility of medical and communication microcircuit training, in treatment of patients with epilepsy, on applying DBS for refractory pseudobulbar affect associated with multiple sclerosis, disruption of nivolumab ddp, management if ibuprofen spray following the induced abrasion ulc, stress induced functionality loss caused by cisplatin against ovarian cancer and others. For example, electrical stimulation of selected cranial nerves has been found to notably affect certain cognitive processes, hence promises such as management of cognitive deficits, dementia, as well as neurobehavioral problems such as depression and epilepsy. This implies that it is possible to inhibit techniques based on exposure to or impacts on the actual organ such as surgery or drug treatment and instead attempt to redirect or control the impact of stimuli passing through the cranial pathways (Showalter-Hall et al., 2021). By means of the BCIs it is also possible to minimize the effects of worsening and even to prepare the damaged area of the brain for standard treatment. In particular, for patients who have lost cognitive control of their muscles, this is where BCIs/EEGs offer more advantageous health interventions than the standard rehabilitation programs available.

The importance of the results of this study is that in these patients, it is possible to combine new tissue engineering and neurology to remodel the patient outcomes. For example, tissue engineering, electrical stimulation, and BCI technology can be combined in creating new approaches of therapy against various neurostructural pathologies. For example, the use of 3D printer to create a scaffold for nerve regeneration is helpful in overcoming the issues faced by damage to or disease within the peripheral or central nervous system. The application of bioprinted scaffold was presented in a case manner in the study of Abdolmaleki et al. (2023) on enhancing aid to the injured nerves by producing bioprinted guides for regenerated axons was advanced (Abdolmaleki et al., 2023).

This method is of particular interest when it comes to the treatment of the extra-pyramidal nervous system cases, which are those whose cure with common methods is quite difficult. Many motor impairment rehabilitation approaches through controlled neural excitations such as brain computer interfaces (BCIs) can be utilized to assist patients in achieving some, if not complete, recovery. They report that individuals with formed tetraplegic paralysis had their functional losses restored using neural interfaces, which underscores the value of merging neural engineering and rehabilitation techniques (Herring et al., 2023).

The author concludes that endeavor substantial progresses were observed toward certain areas, the present papers suggest that a number of issues remain and must be tackled. One of the key difficulties that needs to be addressed is that a vast majority of researches primarily concentrate on particular technologies, such as electric stimulation or BCI, while other potentially synergistic technologies are hardly felt or even remain unmentioned. To provide an example, there has been some progress in the use of electric stimulation to improve the cognitive discrete functions and motor functions of an individual. However, there are challenges related to the application of such electric stimulation. For example, application of electrical stimulation has issues related to cognitive and motor function enhancement for some reasons. Adair et al. (2020) cautioned on the dynamism related to cranial nerve targeting strategies without such threats as any complications or distribution of electrical activity to other parts of the body (Adair et al., 2020).

A part of the problem is that most studies deal with only the immediate outcomes and are devoid of studies with information for the long-term impact of the interventions. For instance, effects of BCIs and electrical stimulation for the few days the patients are in the hospital are achieved, but there is no data regarding how these effects last even after a month of discharge. Particularly, the men address the future of peripheral nerve interfaces development and mention certain problems, e. g. biocompatibility problems connected with devices and possible immune response problems which may be obviated in such work over the coming days (Kim & Romero-Ortega, 2012).

Soon the colorful pictures of how brain-computer interaction or even more complicated neural interactions could be implemented in the rehabilitation settings may prove to be wistful. For example, Ghafoor et al. (2017) have pointed out the inferiorieum base in activating a limited specific area and recommending further research to improve the flexibility, performance and durability of such systems as they are to be fully embraced in the medical community in Ghafoor and colleagues' opinion (Ghafoor et al., 2017).

Prospeare or future research on this topic should look to overcome these limitations by devising much broader strategies aimed at the restoration of the central and peripheral nervous systems. In this vein, there is a need to increase the research into tissue engineering in aspects enhancing nerve regeneration rates. While current scaffolding methods are encouraging, there is a necessity of developing such technologies further with a view of improving their effectiveness and making them more suitable for clinical applications. In neuroregeneration, such as using biodegradable resins instead of nerve conduits (Kim A. Y. and Romero-Ortega, MA., 2012).

Another crucial aspect in the forthcoming scientific research concerns the advancing of interfacing technologies for better interaction of the human brain with computers, which can be embedded in the rehabilitation processes. The emphasis with BCIs has been the elimination of motor recovery although further enhancements with regard to the interface reliability, user-friendliness, and patient convenient-ness are still awaited. Studies should also touch on the area of reducing the interference character of the use of such systems as well as on their better biocompatibility in the concern that they would negatively affect the performance of the person in the long term (Ghafoor et al., 2017).

Future studies should be focused on development of methods that are less intrusive when it comes to the electrical stimulation in brain. Teudt et al. (2007) previously proposed that pulsed infrared radiation as an alternative conventional electrolysis could be used to reduce the risk of damage to tissues and to achieve greater precision in targeting nerves during surgery (Teudt et al., 2007). It is apparent from the discussion that the use of such interventions in therapeutic and surgical settings could be beneficial and improve the overall treatment outcomes.

References

[1] Abdolmaleki, A., Karimian, A., Asadi, A., & Ghanimi, H. A. (2023). 3D bioprinting applications as new technology for nerve regeneration. ZJRMS, 121121. https://dx.doi.org/10.5812/zjrms-121121

[2] Adair, D., Truong, D., Esmaeilpour, Z., Gebodh, N., Borges, H., Ho, L., Bremner, J., Badran, B., Napadow, V., Clark, V., & Bikson, M. (2020). Electrical stimulation of cranial nerves in cognition and disease. Brain Stimulation, 13(2), 354-362. https://dx.doi.org/10.1016/j.brs.2020.02.019

[3] Daniel, C. (2021). Application of cyborgs and enhancement technology in biomedical engineering. Figshare. https://dx.doi.org/10.6084/M9.FIGSHARE.13618970.V1

[4] Emmanuel, B. S. (2022). A study of the effectiveness of monophasic electrical stimulation in enhancing neuromuscular tissue function. IEEE Transactions on Education, 10051226. https://dx.doi.org/10.1109/ITED56637.2022.10051226

[5] Ghafoor, U., Kim, S., & Hong, K. (2017). Selectivity and longevity of peripheral-nerve and machine interfaces: A review. Frontiers in Neurorobotics, 11(59). https://dx.doi.org/10.3389/fnbot.2017.00059

[6] Herring, E., Graczyk, E. L., Memberg, W., Adams, R. D., Fernandez Baca-Vaca, G., Hutchison, B. C., Krall, J. T., Alexander, B. J., Conlan, E. C., Alfaro, K. E., Bhat, P., Ketting-Olivier, A. B., Haddix, C., Taylor, D., Tyler, D., Kirsch, R., Ajiboye, A., & Miller, J. P. (2023). Reconnecting the hand and arm to the brain: Efficacy of neural interfaces for sensorimotor restoration after tetraplegia. medRxiv. https://dx.doi.org/10.1101/2023.04.24.23288977

[7] Huang, Y.-C., & Huang, Y.-Y. (2006). Tissue engineering for nerve repair. BioMedical Engineering OnLine, 5(18). https://dx.doi.org/10.4015/S101623720600018X

[8] Kim, Y., & Romero-Ortega, M. (2012). Material considerations for peripheral nerve interfacing. MRS Bulletin, 37(6), 573-580. https://dx.doi.org/10.1557/MRS.2012.99

[9] Langhals, N., Urbanchek, M., Ray, A., & Brenner, M. (2014). Update in facial nerve paralysis: tissue engineering and new technologies. Current Opinion in Otolaryngology & Head and Neck Surgery, 22(4), 299-306. https://dx.doi.org/10.1097/MOO.0000000000000062

[10] Leach, J., Achyuta, A., & Murthy, S. (2009). Bridging the divide between neuroprosthetic design, tissue engineering and neurobiology. Frontiers in Neuroengineering, 2(18). https://dx.doi.org/10.3389/neuro.16.018.2009

[11] Lei, J. (2023). Strengthen motor imagery for motor disorders patients in metaverse through brain computer interfaces. Journal of Physics: Conference Series, 2580(1), 012029. https://dx.doi.org/10.1088/1742-6596/2580/1/012029

[12] Mackinnon, S. (2018). Discussion: state-of-the-art techniques in treating peripheral nerve injury. Plastic and Reconstructive Surgery, 141(3), 641-643. https://dx.doi.org/10.1097/PRS.0000000000004264

[13] Piscitelli, C. (2024). "Galeno" Neurosurgery Device for Brain Herniation a Multidisciplinary Approach to Complexity. Journal of Clinical Medical Research and Management, 2(2), 111. https://dx.doi.org/10.47363/jcmrm/2024(2)111

[14] Shi, X., Yu, G., & He, D. (2000). An experimental study on physiotherapy for traumatic facial nerve injury. PubMed. https://pubmed.ncbi.nlm.nih.gov/11780532

[15] Teudt, I., Nevel, A., Izzo, A., Walsh, J., & Richter, C. (2007). Optical stimulation of the facial nerve: A new monitoring technique? Laryngoscope, 117(9), 1641-1647. https://dx.doi.org/10.1097/MLG.0b013e318074ec00

[16] Xie, Y., Schneider, K., Ali, S., Hogikyan, N., Feldman, E., & Brenner, M. (2020). Current landscape in motoneuron regeneration and reconstruction for motor cranial nerve injuries. Neural Regeneration Research, 15(8), 1517-1524. https://dx.doi.org/10.4103/1673-5374.276325