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Principles of electrostimulation of the face and neck muscles - a medical and biocybernetic approach

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Streszczenie: *The facial nerve has a tortuous and complex course from the parotid-cerebellar junction to various target sites, with individually varied and complex branching patterns and connections to several other cranial nerves. This makes research-based computational models a key component of modern diagnostics and therapy, as well as patient monitoring and the design of devices to support the above-mentioned processes. To date, no good computational model has been proposed in this area and the concepts presented are in the preliminary research phase. The aim of this study is to develop guidelines for a computational model of electrostimulation of facial and neck muscles in order to improve diagnosis and therapy, but also for the future development of a virtual twin for eHealth.*

Keywords: *computational model, electrostimulation, facial movements, facial nerve branches, mimetic muscles, monitoring, nerve course, nerve innervation.*

Zasady elektrostymulacji mięśni twarzy i szyi - podejście medyczne i biocybernetyczne

Streszczenie: *Nerw twarzowy ma kręty i złożony przebieg od połączenia ślinianki przyusznej i móżdżku do różnych miejsc docelowych, z indywidualnie zróżnicowanymi i złożonymi wzorcami rozgałęzień i połączeniami z kilkoma innymi nerwami czaszkowymi. Sprawia to, że modele obliczeniowe oparte na badaniach są kluczowym elementem nowoczesnej diagnostyki i terapii, a także monitorowania pacjentów i projektowania urządzeń wspierających wyżej wymienione procesy. Do tej pory nie zaproponowano dobrego modelu obliczeniowego w tym obszarze, a przedstawione koncepcje znajdują się we wstępnej fazie badań. Celem niniejszego badania jest opracowanie wytycznych dla modelu obliczeniowego elektrostymulacji mięśni twarzy i szyi w celu poprawy diagnostyki i terapii, ale także dla przyszłego rozwoju wirtualnego bliźniaka dla eZdrowia.*

Slowa kluczowe: *model obliczeniowy, elektrostymulacja, ruchy twarzy, gałęzie nerwu twarzowego, mięśnie mimiczne, monitorowanie, przebieg nerwu, unerwienie nerwu.*

1. INTRODUCTION

The facial nerve is the seventh cranial nerve. It controls the muscles of the face and is responsible for a variety of functions such as expressing emotions, speaking, chewing and swallowing. Damage to the facial nerve can lead to a variety of problems, such as facial asymmetry, difficulty speaking or problems closing the eye. The most common head and neck nerve injuries are facial nerve palsies or recurrent laryngeal nerve palsies. Facial nerve palsy (CN VII) is a functional disorder of the facial nerve involving paralysis of the facial muscles. Correct diagnosis and early treatment are very important to preserve the facial muscles, especially in the absence of signs of return of nerve function. Successful neurotralisation is possible even 19 months after facial nerve paralysis, but already with a combination of electrostimulation therapy and surgical intervention: V-VII nerve transfer and sacral nerve graft. However, despite many studies, the detailed role of electrostimulation therapy in preserving facial muscle function in patients with facial nerve palsy has not been elucidated with the accuracy to develop diagnostic and predictive computational models [1]. Facial nerve electrostimulation is a process that uses electrical impulses to stimulate or regulate facial nerve activity. This type of stimulation can have a variety of medical applications, such as rehabilitation after facial nerve injuries, treatment of certain facial movement disorders, headaches, and in some cases aesthetic facial enhancement. The effects of electrostimulation on the orofacial muscles and on chewing, breathing and swallowing functions have already been shown, including in patients with Down syndrome, with functional increases in chewing, breathing and swallowing performance [2]. The most important seems to be electrical stimulation between denervation and muscle reinnervation where the aim is to reduce the time to completion of reinnervation and to maintain function (improving functional outcomes of the face or larynx). Stimulation then directly affects the denervated muscle and not the innervating nerves [3].

There is a need to develop a standardised and safe protocol for selective surface electrostimulation, including:

- electrode placement,
- selection of stimulation parameters

to achieve selective stimulation of the degenerated muscle while avoiding unwanted simultaneous activation of other ipsilateral or contralateral facial muscles. It is already known that:

- a triangular wave is more effective than a rectangular wave,
- PW pulse width$\geq$50 ms is most beneficial,
- in newly diagnosed patients ($\leq$3 months) the required amplitude is lower ($\leq$5 mA vs. $\leq$15 mA) than in patients with long-term facial paresis (>5 years).
- stimulation sequences show similar results to a single pulse already at lower amplitudes
- correct electrode placement is crucial [4].

This also applies to the use of electrostimulation together with other modalities of influence. Orofacial myofunctional therapy can have a beneficial effect on masticatory function in people with dentofacial deformities, including those undergoing orthognathic surgery, with as few as 10 therapy sessions [5]. Similarly, transcutaneous electrical nerve stimulation (TENS) used alone or in combination with lingual trills in women with vocal nodules has resulted in improved voice quality [6]. Practical recommendations for the diagnostic use of electrodiagnosis of the facial nerve should be more widespread [8]. Evaluation of the variability of the connecting and terminal branches of the facial nerve in humans showed that the peripheral branching and communication of the branches on the face varied between individuals [9].

The aim of this study is to develop guidelines for a computational model of electrostimulation of facial and neck muscles in order to improve diagnosis and therapy, but also for the future development of a virtual twin for eHealth.

2. CONCEPT OF THE COMPUTATIONAL MODEL

The computational model will provide abstract representations for data analysis, decision-making and prediction. In the medical and eHealth context, a virtual twin refers to a virtual representation of a patient or organism that can be used for simulation, health monitoring, predicting drug response, etc.

An AI-based computational model could act as a virtual twin used to analyse and monitor patient health, diagnose diseases, predict drug response and make other healthcare-related decisions. At the moment, there are no reports on a specific facial nerve model and its electrostimulation with such an application.

An electrostimulation model simulates the process of electrostimulation of nerves or tissues in order to understand, analyse, optimise or predict the effects of such stimulation. Such models can be used in research, medical device design, therapy planning and for educational purposes. Examples of applications of electrostimulation models include:

- Scientific simulations: electrostimulation models can help scientists understand how electrical impulses affect nerves and biological tissues. Different stimulation parameters such as frequency, amplitude and duration of pulses can be studied to better understand biological and physiological effects.

- Medical device design: In the development of electrostimulation devices, such as nerve electrostimulators, computer models can be used to test and optimise designs to ensure effective and safe stimulation.
- Therapy optimisation: In physical medicine and rehabilitation, electrostimulation models can help to plan therapy for patients, taking into account individual anatomical and physiological characteristics.
- Theoretical research: Electrostimulation models can help in research into the mechanisms of action of electrostimulation and in analysing the influence of various factors on the effectiveness and safety of stimulation.
- Education: electrostimulation models can be used for educational purposes, both for medical students and professionals, to better understand the principles of electrostimulation and its applications.

Electrostimulation models can be based on mathematical equations describing electrical conductivity in tissues, neuronal behaviour and biological responses to stimulation [10].

Electrostimulation represents the action of electrical energy on two classes of excitable tissues: nerves and muscles. In addition to its diagnostic (e.g. examination of the actual nerve and muscle system) and therapeutic effects, it can also have incidental, aversive and potentially harmful effects. The computational model of electrostimulation reflects the above-mentioned impacts and enables:

- develop standards for human exposure to electric currents of different waveforms,
- determine the classes of nerve fibres led to excitation due to exposure,
- quantify the effects on excitability and unintentional nerve stimulation due to exposure,
- compare safety margins between electrostimulation thresholds of sensory and motor neurons [10].

The most commonly used model is the SENN (Spatially Extended Nonlinear Node) model reflecting the interaction of electrical energy with myelinated neurons. However, this software contains only a simple model for estimating the electrical dose at the site of nerve or muscle stimulation (so-called electrical dosimetry for electrostimulation devices) based on a threshold factor, i.e. a numerical estimate of electrical stimulation correlated with the volume of tissue containing neurons potentially stimulated by the electrical stimulus [10]. The aforementioned model standardises the understanding of electrical dose, but has no predictive value for the entire therapy, hence the need for further development of the aforementioned model [11-14].

3. DISCUSSION

Electrostimulation of the facial nerve is a medical procedure and should be carried out by qualified specialists. Each case requires an individual assessment and approach.

To date, no publications have been observed on the computational modelling of electrostimulation of facial and neck muscles or the application of AI/ML in this area.

The solution to this problem is hampered by the fact that in previous studies it has not been possible to uniformly functionally assign individual facial nerve branches to well-defined facial movements. On the other hand, it has been identified:

- the need for individual facial nerve assessment to ensure correct stimulation of peripheral nerve branches for triggering different muscle functions for models and control of bionic devices,
- temporo-facial division supplying the forehead and eye area,
- cervicofacial division supplying the mouth and neck region and, in some patients, also the nasal and zygomatic region,
- orbicularis oculi muscle function - stimulation of a branch of the temporo-facial division causes the eye to close,
- function of the nasal, zygomatic, orbicularis oris and depressor anguli oris muscles - stimulation of a branch of the cervicofacial nerve leads to a muscular response of the midface and around the mouth,
- joint monitoring and computational modelling of the facial nerve must be tailored to the physiology and pathology of the individual patient [15].

Studies of the distribution of the terminal branches of the facial nerve to the facial muscles are rare, and they have revealed at least five multiple anomalies that are not found in textbooks and atlases [16]. A deeper understanding of these anomalies and their inclusion in computational models will help to improve the hitherto unsatisfactory results of treatment of, for example, primary eyelid spasm [17]. Investigating the connections between the facial nerve and other nerves (from the brainstem to the peripheral branches in the face) is important for proper diagnostic (clinical examination) and surgical procedures in these areas, including reconstructive surgery of the face, neck and nerve transfer procedures. It also carries with it a better understanding of the pathophysiology of craniofacial, skull base and neck disorders and injuries [18]. Three different classifications of extraocular facial nerve course have also been proposed, based on two main divisions:

- temporofacial,
- cervicofacial.

Divided into five terminal branches:

- temporal,
- zygomatic,
- buccal,
- marginal or mandibular,
- cervical.

Patterns were based on types, the most common of which are:

- type 3 (about 20% of cases) with connections between the temporal, zygomatic and buccal branches,
- type 8 (about 20% of cases) with connections between temporal, zygomatic, buccal and mandibular branches [19].

A high-resolution ultrasound (HRUS) protocol for quantitative and qualitative assessment of facial muscles has also been proposed [20]. The above-mentioned efforts remain insufficient, hence the need to develop both a computational model and a virtual twin of the facial nerve for each patient. The tunnelling procedure for peripheral facial nerve palsy caused by extracranial facial nerve damage after ventriculoperitoneal shunting must be performed particularly carefully in children [21]. Mapping of the facial nerve by surface electrostimulation in healthy individuals and patients (e.g. with postparetic facial synkinesis) can help identify facial areas for selective stimulation (including for prostheses and bionic stimulators). The number of facial stimulation points investigated exceeds 1,800 and has to be implemented with high accuracy at a stimulation threshold of 4.1±0.5 mA on average for healthy subjects. In healthy subjects, such selective electrostimulation was possible for pulling up the corner of the mouth in 65-75% of cases and for the other areas in >80% of cases [22]. Facial rejuvenation surgery is a distinct group of procedures that need to be well prepared neuroanatomically [23].

Sometimes the behaviour is due to context rather than the activation of a primary control, such as unilateral blinking - such behaviour may be related to activation of the anterior temporal area due to projections to the ipsilateral frontal, periaqueductal, occipital, limbic and cerebellar areas, interestingly occurring more frequently in women with temporal lobe epilepsy [24]. Electrophysiological monitoring of the facial nerve is becoming an important part of diagnosis and therapy, assisting in the functional behaviour of the facial nerve for the diagnostician, therapist and surgeon [25]. The creation of virtual 'safety maps' (including for supraorbital keyhole access - SOKA) improves patient safety and favourable prognosis when accessing the anterior cranial fossa. In this case, facial nerve damage is only observed in at most 5.6 per cent of patients, compared with up to approx. 10% [26]. The reconstruction of complex facial nerve defects (e.g. after cancer surgery) is also becoming a key problem in severe conditions, which requires individual solutions and reliance on models and predictions. An example of this is the trifurcation technique, where the cervical cutaneous plexus provides a long nerve graft to fill the gap between the proximal facial nerve stump and the peripheral branches with a low degree of synkinesis [27].

3.1. Limitations of previous studies

Caveats have been observed regarding the use of electrostimulation, Some negative stimulation results are not suitable for denervated muscle fibres. For the aforementioned reasons, it is necessary to know the neurophysiology of denervated facial and laryngeal muscles compared to innervated muscles. It is necessary to demonstrate in larger controlled studies that effective and tolerable electrostimulation of the facial and laryngeal muscles is possible without side effects, furthermore it facilitates nerve regeneration and improved functional outcomes [3]. It is possible that the current patient selection criteria for electrostimulation are not able to identify all patients unresponsive to this therapy.

3.2. Directions for further studies

Essential directions for further research include:

- the development of prospective studies, complex due to the diversity of disease subtypes [28],
- greater use of computational models, not only of the physiological and pathological mechanisms themselves, but also of damage, treatment effects and recovery, including calculation of treatment parameters and prediction of effects, up to and including the digital twin of the facial nerve [29-31],
- the development of reliable non-invasive diagnostic and predictive tools [36-39],
- development and presentation of care, diagnosis, treatment and prediction of treatment outcome on this basis [36-38],

- classification of methods and techniques,
- the development of clinical guidelines [39-43].

4. CONCLUSIONS

The facial nerve has a tortuous and complex course from the parotid-cerebellar junction to various target sites, with individually varied and complex branching patterns and connections to several other cranial nerves. This makes research-based computational models a key component of modern diagnostics and therapy, as well as patient monitoring and the design of devices to support the above-mentioned processes. To date, no good computational model has been proposed in this area and the concepts presented are in the preliminary research phase.

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