Intra-oral and peri-oral electronic devices
An overview of current therapeutic and diagnostic systems
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The functions and organ systems of the human body are, to a significant extent, controlled by electrical signals that travel along the nerves. Electronic medical devices are aimed at controlling biological processes and treat disease by modulating these electrical impulses. These devices may assist in the therapy of conditions that are currently untreatable or resistant to other therapy methods. They may deliver signals that travel along the nerves.

Electronic medical devices are aimed at controlling biological processes, and fewer side-effects than conventional pharmaceutical products do.

In the last few decades, a variety of wearable electronic medical devices have been introduced to the market. Examples of such devices include neuro-stimulators, cardiac pacemakers, implantable cardiac defibrillators, cochlear implants and retinal implants. These devices are used to address a variety of conditions, such as brain disorders (including epilepsy), Parkinson’s disease, traumatic brain injury, stroke, psychiatric disorders, etc.), chronic pain conditions (addressed through e.g. spinal cord stimulators), incontinence, cardiovascular disorders (including heart failure, angina and peripheral vascular disease), deafness and blindness.

A number of vital structures located in the oral cavity region are controlled by the nervous system, such as the salivary glands and the oral musculature. Given the largely proven diagnostic and therapeutic value of electronic devices, it is surprising that only a few intra- and peri-oral electronic medical devices have been released to the market. Moreover, in contrast to the highest risk devices and are, therefore, subject to the highest level of regulatory control. However, recently the FDA has classified a small number of these types of devices as Class II devices, which are lower risk devices than Class III and require less regulatory control to provide reasonable assurance of the device’s safety and effectiveness. Nevertheless, those devices have to meet special controls, which are requirements intended to address the unique concerns of specific types of devices. Some examples are as follows:

- On 11 March 2014, the FDA allowed marketing of an electronic device as a preventative treatment for migraine headaches (Cefaly, CEFALY Technology). The portable, battery-powered prescription device resembles a plastic headband worn across the forehead and atop the ears. The user positions the device in the centre of the forehead, just above the eyes, using a self-adhesive electrode. The device applies an electrical current to the skin and underlying body tissue to stimulate branches of the trigeminal nerve, which has been associated with migraine headaches.

Previously, it was a Class III device. This intra-oral device (more details later in the article) is restricted to prescribed use upon prescription of a dental practitioner or physician.

- On 22 January 2016, the FDA announced a proposed administrative order to reclassify cranial electrotherapy stimulator devices intended to treat incontinence and/or anxiety, from Class III to Class II (special controls).

Examples of three electronic intra- and peri-oral devices that are available are covered in the paragraphs that follow.

The TheraMon® system consists of (a) a micro-sensor that measures and stores the temperature readings, that is wearing time data of the removable therapeutic device (Fig. 8); (b) a reading station that reads the memory of the micro-sensor using radio-frequency identification technology and transfers the data to a computer via a USB cable (Fig. 2); and (c) assessment software that represents the wearing time in a diagram. TheraMon® is a class I medical product (lowest level of risk) that does not claim any medical, therapeutic or diagnostic functionality.

Sensors like TheraMon® can be implemented in mandibular advancement devices (MADs), which are increasingly being prescribed as an alternative to the use of continuous positive airway pressure (CPAP) systems in the treatment of obstructive sleep apnoea. Studies have shown that MADs are preferred by patients and, thus, compliance with treatment may be greater than for CPAP. However, compliance with the treatment can be better measured in the CPAP system, as the built-in processor allows follow-up of the actual hours of use of the mask. In contrast, conventional MADs lack this control system and, thus, objective verification of compliance is not possible. Therefore, a microchip for thermal sensing that is inserted into a MAD can provide this missing ability to measure compliance objectively.

In a blind prospective clinical study of three months duration, the safety and feasibility of objective measurement of compliance with MAD wearing was evaluated.

SaliPen device in place, reaching the lingual nerve region bilaterally.—Fig. 2: Theramon® microsensor and a removable device to which it will be attached.—Fig. 3: SaliPen device.—Fig. 4: SaliPen device in place, reaching the lingual nerve region bilaterally.—Fig. 5: SaliPen device.—Fig. 6: SaliPen usage.

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1. Intra-oral diagnostic device. Sensor for mandibular advancement devices.

TheraMon® (MC Technology) is a microchip specially designed to be embedded in removable orthodontic and dental sleep appliances. According to the manufacturer, the sensor reports the temperature of the device and its surrounding area. This enables assessment of whether the sensor (embedded into the oral appliance) is being worn in the oral cavity or was outside of the mouth.

The TheraMon® microsensor and a removable device to which it will be attached.—Fig. 1: Theramon® reading station and microsensor, with a removable intraoral device.—Fig. 2: SaliPen device.
worn by 43 patients with an established diagnosis of respiratory sleep disorders. No adverse events related to the micro-sensors were recorded, nor were problems in reading of the compliance data. In this study, the mean time of Linus use was 6 ± 2.1 hours per day, with an 86 per cent compliance rate after a three month follow-up. Statistical analysis found no differences between the data on objective and subjective use of Linus. In conclusion, the results demonstrated the safety and the efficacy profile of the objective measurement of compliance with MAD wearing.

2. Intra-oral therapeutic device: Electrostimulation device to treat xerostomia

The commonly accepted clinical definition of xerostomia is the subjective sensation of dry mouth. The presence of xerostomia may indicate that salivary output is decreased or altered, placing patients at a higher risk of developing a number of oral diseases and complications.

Increasing secretion of natural saliva is the most efficient means of relieving xerostomia, as natural saliva both alleviates dryness and contains essential dental decay-fighting factors and other components critical for oral health. The prevalence of xerostomia in the adult population is estimated at 10 per cent.

Salivary gland secretion is regulated by the autonomic nervous system, by means of the salivary reflex. The latter is composed of (a) salivary nuclei, located in the brain, (b) afferent nerve fibres, carrying stimuli (such as taste and mastication) from the peripheral to the salivary nuclei, and (c) efferent nerve fibres, conveying stimulatory signals from the salivary nuclei to the salivary glands. Application of electrical impulses to one or more of the three components of the salivary reflex increases salivary secretion.

Salitwell® has developed a line of intra-oral electrostimulation devices for which the principle of action is based on applying stimulatory signals in the vicinity of the lingual nerve, which is the main nerve controlling salivary function, as it carries both afferent and efferent fibres. Electrostimulation intensifies the impulses transmitted through the afferent and efferent nerve fibres, inducing the salivary glands to secrete more saliva. To this end, the device electrodes are placed at the lingual side, close to the mandibular third molar, an advantageous location owing to the close proximity to the lingual nerve, allowing effective stimulation by the use of lower voltage and current [Fig. 4].

The most recently developed device (SalPen) has an intra-oral stimulating unit and an extra-oral control unit [Fig. 5]. The electrodes protrude at the end of two flexible silicone arms that are gently inserted underneath the tongue. In a typical usage profile, due to its long lasting effect, the device is worn about 4 times a day and about 4 minutes every time [Fig. 6].

A double-blind study, carried out at three medical centres in Europe, tested the device performance with short-term use, using a built-in moisture sensor. The primary outcome was measured oral dryness changes as a result of 10 minutes of wearing the device were assessed and compared between the usage of the device either switched on or switched off. Twenty-three patients with xerostomia due to different causes (primary Sjögren’s syndrome, radiotherapy, medication-induced, graft-versus-host disease and idiopathic) were evaluated. The decrease in oral dryness (as measured by the moisture sensor) was significantly superior (p < 0.0001) when induced by the device in switched-on mode. No significant side-effects were observed.

In a multi national randomised clinical trial, long-term (6 months) intra-oral electrostimulation was tested in a mixed sample of xerostomia patients (Sjögren’s syndrome, radiotherapy, medication-induced, graft-versus-host disease and idiopathic). In Stage I of the study, switched-on versus switched-off devices were compared, for a period of one month in a double-blind design (96 patients). In Stage II, immediately after Stage I, the xerostomia-relieving effects of the switched-on device only, were assessed in an open label study (96 patients).

The results of Stage I show that the patient-reported degree of oral moisture improved by 26 per cent when the device was switched on (with a statistical significance level of p < 0.0001) versus an 18 per cent improvement when switched off. The results of Stage II show that the level of self-perceived oral moisture improved by 34 per cent (p < 0.0001) and the amount of collected saliva increased by 25 per cent (p < 0.0001) at rest and by 18 per cent (p < 0.0001) during mastication. No severe or irreversible systemic or local adverse effects were observed at either stage of the trial.
Bruxism is the most well-known form of oral parafunction. Parafunctions are movements of the masticatory system that are considered outside or beyond normal function. The prevalence of bruxism in the adult population is estimated at 8 per cent, however, as many individuals may be unaware of this condition, the occurrence is most likely higher.

Unfortunately, people with sleep bruxism usually are not aware that they bruix; so they are not diagnosed until complications occur. That is why it is important to diagnose sleep bruxism as early as possible and to seek appropriate treatment. Bruxism is usually diagnosed based on clinical examination of the teeth, complaints of jaw and masticatory pain, and reports by the bed partner of grinding noises. Patients suspected of bruxism are not routinely referred to the sleep laboratory due to its high cost. Thus, clinical and experimental data are scarce and there is no accepted gold standard for a definitive, objective diagnosis.

BiteStrip (SLP) is a diagnostic tool that can assist the clinician in detecting bruxism and assessing over time the effectiveness of the therapy delivered to treat the disorder. It is a miniature single-use electronic device designed as a screener for bruxism (Fig. 7). It consists of three electromyography (EMG) electrodes and an amplifier to acquire masticatory muscle signals, a central processing unit with real-time software that detects and analyses EMG Patterns, and a display that exhibits the measurements in the morning. All elements are integrated on a single flexible substrate.

At bedtime, patients are instructed to attach the device over the mandible to the cheek, to activate it and to perform a series of maximal strength clenching and grinding activities in order to establish an individual threshold for the nighttime monitoring (Fig. 8). The device must be worn for at least 5 hours of sleep. In the morning, patients deactivate the device and wait for approximate 20 minutes for the bruxism index (number of bruxing events per hour of recording) to be displayed.

The BiteStrip device was used in a before-and-after experimental clinical study with the objective of evaluating the effect of a MAD on sleep bruxism and sleep scores. After a habituation period of one week, sleep bruxism scores were taken at baseline and after use of the MAD for 30 days. Scores were compared using BiteStrip, which registered the number of contractions of the unilateral masticate muscle after a 5 hours period, giving a severity score of 0 to 3 after the registrations. In order to assess sleep, the Sleep Assessment Questionnaire, a screening tool with scores ranging from 0 to 88, was administered before and after use of the MAD.

Twenty-eight subjects (13 women and 15 men; mean age of 41.9 ± 12) with a clinical history of sleep bruxism and no spontaneous TMD pain were selected. The clinical diagnosis of either moderate or severe sleep bruxism was further confirmed through use of BiteStrip (score of 2 or 3) at baseline. A 30-day follow-up period was used for evaluation. Both methods were validated against polysomnography. In addition, common signs and symptoms of TMD based on the Research Diagnostic Criteria for Temporomandibular Disorders were evaluated before and after use to assess the side-effects of the MAD. The results showed a statistically significant improvement in both sleep bruxism and sleep scores based on BiteStrip and the Sleep Assessment Questionnaire. Concerning the signs and symptoms of TMD, there was a significant reduction in TMD pain sounds, as well as in masticatory and temporalis tenderness to palpation. In summary, the improvement measured by BiteStrip was the same as the improvement assessed by other methods.

Conclusion

In conclusion, implementation of electronically based intra- and peri-oral therapeutic and diagnostic devices creates new possibilities for all kinds of novel applications for which the power of electronics and related technologies (software, wireless communications) is harnessed to provide better and personal medical services at lower costs.