PAIN MANAGEMENT
WITH
PULSED ELECTROMAGNETIC FIELD (PEMF) TREATMENT

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The issue of pain treatment is an extremely urgent health and socio-economic problem. Pain, in acute, recurrent and chronic forms, is prevalent across age, cultural background, and sex, and costs North American adults an estimated $10,000 to $15,000 per person annually. Estimates of the cost of pain do not include the nearly 30,000 people that die in North America each year due to non-steroidal anti-inflammatory drug-induced gastric lesions. 17% of people over 15 years of age suffer from chronic pain that interferes with their normal daily activities. Studies suggest that at least 1 in 4 adults in North America is suffering from some form of pain at any given moment. This large population of people in pain relies heavily upon the medical community for the provision of pharmacological treatment. Many physicians are now referring chronic pain sufferers to non-drug based therapies, that is, "Complementary and Alternative Medicine," in order to reduce drug dependencies, invasive procedures and/or side effects. The challenge is to find the least invasive, toxic, difficult and expensive approach possible.

The ability to relieve pain is very variable and unpredictable, depending on the source or location of pain and whether it is acute or chronic. Pain mechanisms are complex and have peripheral and central nervous system aspects. Therapies should be tailored to the specifics of the pain process in the individual patient. Psychological issues have a very strong influence on whether and how pain is experienced and whether it will become chronic. Most effective pain management strategies require multiple concurrent approaches, especially for chronic pain. It is rare that a single modality solves the problem.

Static or electromagnetic fields have been used for centuries to control pain and other biologic problems, but scientific evidence of their effect had not been gathered until recently. This review explores the value of magnetic therapy in rehabilitation medicine in terms of static magnetic fields and time varying magnetic fields (electromagnetic). A historical review is given and the discussion covers the areas of scientific criteria, modalities of magnetic therapy, mechanisms of the biologic effects of magnetic fields, and perspectives on the future of magnetic therapy.

In the past few years a new and fundamentally different approach has been increasingly investigated. This includes the use of magnetic fields (MF), produced by both static (permanent) and time-varied (most commonly, pulsed) magnetic fields (PEMFs). Fields of various strengths and frequencies have been evaluated. There is as yet no “gold standard”. The fields selected will vary based on experience, confidence, convenience and cost. Since there does not appear to be any major advantage to any one MF application, largely because of the unpredictability of ascertaining the true underlying

source of the pain, regardless of the putative pathology, any approach may be used empirically and treatment adjusted based on the response. After thousands of patient-years of use globally, very little risk has been found to be associated with MF therapies. The primary precautions relate to implanted electrical devices and pregnancy and seizures with certain kinds of frequency patterns in seizure prone individuals.

Magnetic fields affect pain perception in many different ways. These actions are both direct and indirect. Direct effects of magnetic fields are: neuron firing, calcium ion movement, membrane potentials, endorphin levels, nitric oxide, dopamine levels, acupuncture actions and nerve regeneration. Indirect benefits of magnetic fields on physiologic function are on: circulation, muscle, edema, tissue oxygen, inflammation, healing, prostaglandins, cellular metabolism and cell energy levels.

Most studies on pain use subjective measures to quantitate baseline and outcome values. Subjective perception of pain using a visual analogue scale (VAS) and pain drawings is 95% sensitive and 88% specific for current pain in the neck and shoulders and thoracic spine.

Measured pain intensity (PI) changes with pain relief and satisfaction with pain management. A 5%, 30%, and 57% reduction in PI correlated with "no," "some/partial," and "significant/complete" relief. If initial PI scores were moderate/severe pain (NDS > 5), PI had to be reduced by 35% and 84%, to achieve "some/partial" and "significant/complete" relief, respectively. Patients in less pain (NDS < or = 5) needed 25% and 29% reductions in PI. However, relief of pain appears to only partially contribute to overall satisfaction with pain management.

Several authors have reviewed the experience with PEMFs in Eastern Europe and the West. PEMFs have been used extensively in many conditions and medical disciplines. They have been most effective in treating rheumatic disorders. PEMFs produced significant reduction of pain, improvement of spinal functions and reduction of paravertebral spasms. Although PEMFs have been proven to be a very powerful tool, they should always be considered in combination with other therapeutic procedures.

Since the turn of this century, a number of electrotherapeutic, magnetotherapeutic and electromagnetic medical devices have emerged for treating a broad spectrum of trauma, tumors and infections with static and PEMFs. Their acceptance in clinical practice has been very slow in the medical community. Practitioner resistance seems largely based on confusion of the different modalities, the wide variety of frequencies employed (from ELF to microwave) and the general lack of understanding of the biomechanics involved. The current scientific literature indicates that short, periodic exposure to pulsed electromagnetic fields (PEMF) has emerged as the most effective form of electromagnetic therapy.

The ability of PEMFs to affect pain is dependant on the ability of PEMFs to positively affect human physiologic or anatomic systems. Research is showing that the human nervous system is strongly affected by therapeutic PEMFs. Behavioral and physiologic

responses of animals to static and extremely low frequency (ELF) magnetic fields are affected by the presence of light. Light strengthens the effects of PEMFs.

One of the most reproducible results of weak, extremely low-frequency (ELF) magnetic field (MF) exposure is an effect upon neurologic pain signal processing. PEMFs have been designed for use as a therapeutic agent for the treatment of chronic pain in humans. Recent evidence suggests that PEMFs would also be an effective complement for treating patients suffering from acute pain. Static magnetic field devices with strong gradients have also been shown to have therapeutic potential. Specifically placed static magnets reduce neural action potentials and alleviate spinal mediated pain. The placebo response may explain as much as 40% of an analgesia response. The central nervous system mechanisms responsible for the placebo response are an appropriate target for magnetic therapies. Magnetic field manipulation of cognitive and behavioral processes is seen in animal behavior studies and in humans. This may also be one of the mechanisms of the use of MFs in managing pain.

Some of the mechanisms of PEMF effects

Magnetotherapy is accompanied by an increase in the threshold of pain sensitivity and activation of the anticoagulation system. PEMF treatment stimulates production of opioid peptides; activates mast cells and increases electric capacity of muscular fibers. Long bone fractures that did not unite over 4 months to 4 years are repaired in 87% of cases with 14-16 hr of daily PEMF treatment. Several of these devices are FDA approved. PEMF of 1.5- or 5-mT field strength, proved helpful edema and pain before or after a surgical operation.

PEMF for 15-360 minutes increases amino acid uptake about 45%. PEMF for 2 hour induces changes in transmembrane energy transport enzymes, allowing energy coupling and increased biologic chemical transport work.

The density of pigeons' brain *mu* opiate receptors decreases by about 30% and therefore their pain perception. A 2 hr exposure of healthy humans was found to reduce pain perception and decreased pain-related brain signals. Biochemical changes were found in the blood of treated patients that supported the pain reduction benefit.

Normal standing balance is subject to control by the vestibular area of the brain. PEMF couple with muscular processing or upper body nervous tissue functions. 200-uT PEMFs cause a significant improvement in normal standing balance in adult (18-34 year old) humans. Further evidence of the sensitivity of the nervous system on MFs.

Various MFs with different characteristics reduce pain inhibition in various species of animals including land snails, mice, pigeons, as well as humans. 0.5 Hz rotating MF, 60 Hz ELF magnetic fields and even MRI reduces analgesia induced by both exogenous opiates (i.e. morphine) and endogenous opioids (i.e. stress-induced). Reduction in stress-induced analgesia can be obtained not only by exposing animals to a variety of different magnetic fields, but also after a short-term stay in a near-zero magnetic field. This

suggests that even for magnetic field, as for other environmental factors (i.e. temperature or gravity), alterations in the normal conditions in which the species has evolved can induce alterations in physiology as well as in behavior.

MFs applied to the head or to an extremity, for from 1 to 60 minutes, with intervals from several minutes to several hours, randomly sequenced with sham exposures allowed study of brain reactions by various objective measures. From these multiyear studies, the brain shows a non-specific initial response. The changes were "modulatory", meaning that the brain was found to sense EMF exposures vs. sham exposures. The sensory reactions were a weak pain, tickling, pressure, etc. sensations, mediated by the body's peripheral sensory systems. Reactions could be prevented by local anesthesia of the exposed area. EEGs showed increased low-frequency rhythms, more pronounced when brain damage was present. This explains the common perception of relaxation and sleepiness with MFs. Cell analysis showed that all types of brain cells react to EMFs but astrocytes were most sensitive. They are involved in memory processes and slow wave brain activity.

The benefits of PEMF use may last considerably longer than the time of use. In rats, a single exposure produces pain reduction both immediately after treatment and at 24 hrs after treatment. The analgesic effect is still observed at 7th and 14th day of repeated treatment and even up to 14 days after the last treatment.

PEMFs promote healing of soft tissue injuries by reducing edema and increasing resorption of hematomas. Low frequency PEMFs reduce edema primarily during treatment sessions. PEMFs at very high frequencies (PRFs) for 20-30 minutes cause edema decreases lasting several hours. PRFs induce vasoconstriction at the injury site. They displace negatively charged plasma proteins found in traumatized tissue. This increases lymphatic flow, an additional factor in reducing edema.

In rats exposed for 20 min daily on 3 successive days to PEMFs of 50 mG, the pain threshold increased progressively over the 3 days. The pain threshold following the third magnetic field exposure was significantly greater than those associated with morphine and other treatments. Brain injured and normal rats both showed a 63% increase in mean pain. PEMFs may be very helpful in patients with closed head injuries. The mechanism probably involves the longer acting endorphins rather than enkephalins.

Chronic pain is often a result of aberrantly functioning small neural networks involved in self-perpetuated neurogenic inflammation. High intensity pulsed magnetic stimulation (HIPMS) noninvasively depolarizes neurons and can facilitate recovery following injury. Patients suffering from posttraumatic or postoperative low-back pain, reflex sympathetic dystrophy, peripheral neuropathy, thoracic outlet syndrome and endometriosis had pain relief. Up to ten,10-min exposures to 1.17 T at a rate of 45 pulses/minute were applied to the areas of maximal pain for 6 treatments. One patient became pain free after 4 HIPMS treatments. All patients reported some pain relief. Maximum pain relief occurred 3 hr after treatment. Two patients had complete pain relief and 3 had partial pain relief that lasted for 4 months. The others had pain relief that lasted for 8-72 hours.

Even weak AC magnetic fields affect pain perception and pain-related EEG changes in humans. A 2 hour exposure to 0.2-0.7G ELF magnetic fields caused a significant decrease in pain-related EEG patterns.

Pain relief mechanisms vary by the type of stimulus used. For example, needling to the pain-producing muscle, application of a static magnetic field or external qigong or needling to an acupuncture point all reduce pain but by different mechanisms. Pain could be induced by reduction of circulation in muscle and reduced by recovery of circulation. Pain mediating substances are accumulated in a muscle under reduced circulation and reversed with restoration of circulation. This is why chronic muscle tension is a frequent cause of chronic pain. The effect of a static magnetic field or external qigong is mediated by enhanced release of acetylcholine as a result of activation of the cholinergic vasodilator nerve endings in a muscle artery. Needling an acupuncture point is probably induced by a somato-autonomic reflex through the brain, in the anterior hypothalamus.

In normal subjects, a magnetic stimulus over the cerebellum reduces the size of responses evoked by cortical stimulation. Suppression of motor cortical excitability is reduced or absent in patients with a lesion in the cerebellum or cerebellar nerve pathways. Magnetic stimulation over the cerebellum produces the same effect as electrical stimulation, even in ataxic patients and may be useful for the pain associated with muscle spasticity.

Clinical benefits

In diabetic neuropathy, PEMF treatment every day for about 12 minutes, improves pain, paresthesias and vibration sensation and increases muscular strength in 85% of patients compared to controls.

One author reported that, of treated patients followed for 2-60 months, better results happened in patients with post-herpetic pain and those simultaneously suffering from neck and low back pain.

Chronic pain is often accompanied with or results from decreased circulation or perfusion to the affected tissues, for example, cardiac angina or intermittent claudication. PEMFs have been shown to improve circulation. Skin infrared radiation increases due to immediate vasodilation with low frequency fields and increased cerebral blood perfusion in animals. Pain syndromes due to muscle tension and neuralgias improve.

The results of the treatment depend not only on the parameters of the fields but also on the individual sensitivity of the person. The most effective results in clinical use were found with extremely ultra low frequency PEMFs.

Back, neck and shoulder pain

Chronic low back pain affects approximately 15% of the United States (US) population during their lifetime, with 93 million lost work days and a cost of more than $5 billion per year. Lumbar arthritis is a very common cause of back pain. 35-40 mT PEMFs, for 20 minutes daily for 20-25 days for back pain gives relief or elimination of pain, improves results from other rehabilitation and improves secondary neurologic symptoms. Continuous use over the treatment episode works best, in about 90-95% of the time. Control patients only show a 30% improvement.

PEMF of 5 to 15 G, from 7 Hz to 4 kHz used at the site of pain and related trigger points for 20 to 45 minutes also helps. Some patients remain pain free 6 months after treatment. Some return to jobs they had been unable to perform. Short term effects are thought due to decrease in cortisol and noradrenaline and an increase serotonin, endorphins and enkephalins. Longer term effects may be due to CNS and/or peripheral nervous system biochemical and neuronal effects in which correction of pain messages occurs and the pain is not just masked as in the case of medication.

Back pain or whiplash syndrome treated PEMF twice a day for two weeks along with usual pain medications relieves pain in 8 days vs. 12 days in the controls. Headache is halved in the PEMF group and neck and shoulder/arm pain improved by one third versus just medications alone.

Permanent magnetic therapy can also be useful in reducing chronic muscular low back pain. Treatment with a flexible permanent magnetic pad for 21 days reduces pain 6 times more than placebo. This has been effective for herniated lumbar discs, spondylosis, radiculopathy, sciatica and arthritis. Pain relief is sometimes experienced as early as 10 minutes or in some cases takes as long as 14 days.

Low-power pulsed short wave 27 Hz diathermy has successfully treated persistent neck pain and improved mobility. The neck pains lasted longer than 8 wk and did respond to at least 1 course of nonsteroidal anti-inflammatory drugs. A miniaturized, 9V battery-operated, diathermy generator was fitted into a soft cervical collar. Treatment is for 3-6 weeks, 8 hr daily. Analgesics can be used as needed and nonsteroidal anti-inflammatory drugs. 75% of patients improve in range of motion and pain within 3 wk of treatment.

For neck pain, PEMFs may have more benefit, compared to physical therapy, for both pain and mobility.

Other pain applications

High frequency PEMF of 10-15 single treatments every other day either eliminates or improves, even at 2 weeks following therapy, 80% of patients with pelvic inflammatory disease, 89% with back pain, 40% with endometriosis, 80% with postoperative pain, and 83% with lower abdominal pain of unknown cause.

In dentistry, PEMFs have also been found only slightly useful in treating dental pain, jaw muscle spasms and swelling during wisdom tooth extraction with a high frequency

system. As is often seen in pain studies, a placebo response is high, 30-40% of the time. In periodontal disease bone resorption may be severe enough to require bone grafting. Grafting is followed by moderate pain peaking several hours afterwards. Repeated PEMF exposure for two weeks eliminates pain within a week. Even single PEMF exposure to the face for 30 minutes of a 5mT field and conservative treatment produces much lower pain scores vs. controls.

Pelvic pain of gynecological origin was also found to be benefited by a different high voltage, high frequency system. This includes ruptured ovarian cysts, postoperative pelvic hematomas, chronic urinary tract infection, uterine fibrosis, dyspareunia, endometriosis and dysmenorrhea. Treatment times vary from 15 to 30 minutes on subsequent or alternate days. 90% of patients experience marked, rapid relief from pain with pain subsiding within 1-3 days. Most of these patients don't require supplementary analgesics.

Post-herpetic neuralgia (PHN), a very common and painful condition, which is often medically-resistant, responds to PEMF for 20-30 minutes daily for 19 treatments over 34 days. The PEMF is a 4-16 Hz and 0.6-T samarium/cobalt magnet system surrounded by spiral coil pads with a maximum 0.1-T pulse at 8 Hz pasted on the pain/paresthesia areas or over the spinal column or limbs. Treatments continue until symptoms improve or an adverse side effect occurred. PEMF therapy is effective in 80%. No pain was made worse. This treatment approach shows that treatment for pain problems may either be localized to the pain or done over the spinal column or limbs, away from the pain.

PEMFs applied to the inner thighs for at least 2 wk is effective short-term therapy for migraine. Greater reduction of headache activity is achievable with longer exposure. PEMF using a high frequency signal to the inner thigh femoral artery area for 1 hr/day, 5 day/wk, for 2 weeks decreases headache. One month after a treatment course, 73% of patients report decreased headache activity vs. only half of those receiving placebo treatment. Another 2-wk of treatment after the 1-month follow-up gives an additional 88% decrease in headache activity. If there is no additional treatment after an initial course 72% still show a benefit. Placebo patients getting active treatment afterwards report much better additional improvement in headache.

Patients suffering from headache treated with a PEMF after failing acupuncture and medications, applied to the whole body, 20 min/day for 15 days get effective relief of migraine, tension and cervical headaches at about one month after treatment. They have at least a 50% reduction in frequency or intensity of the headaches and reduction in analgesic drug use. Poor results are seen in cluster and posttraumatic headache.

Chronic pain frequently presented by postpolio patients can be relieved by application of magnetic fields applied directly over trigger points using 300 to 500 G static magnets for 45 minutes.

Orthopedic or musculoskeletal uses

The use of PEMFs is rapidly increasing and extending to soft tissue from its first applications to hard tissue. EMF in current orthopedic clinical practice is used to treat delayed and non-union fractures, rotator cuff tendinitis, spinal fusions and avascular necrosis, all of which can be very painful. Clinically relevant response to the PEMF is generally not always immediate, requiring daily treatment for several months in the case of non-union fractures. PEMF signals induce maximum electric fields in the mV/cm range at frequencies below 5 kHz. Pulse radiofrequency fields (PRF) consist of bursts of sinusoidal waves in the short wave band, usually in the 14-30 MHz range. PRF induces fields in the V/cm range. PRF signals have higher field strengths than PEMFs. PRF signals have low frequency bursts nearly equivalent in size to PEMFs. This means that PRF signals have a broader band. PRF applications are best for reduction of pain and edema. The tissue inflammation that accompanies the majority of traumatic and chronic injuries is essential to the healing process, however the body often over-responds and the resulting edema causes delayed healing and pain. For soft tissue and musculoskeletal injuries and post-surgical, post-traumatic and chronic wounds, reduction of edema is thus a major therapeutic goal to accelerate healing and associated pain. Double-blind clinical studies have now been reported for chronic wound repair, acute ankle sprains, and acute whiplash injuries. PRFs accelerated reduction of edema in acute ankle sprains by 5-fold. Response to MFs is during or immediately after treatment of acute injuries. Responses are significantly slower for bone repair. The voltage changes induced by PRF at binding sites in macromolecules affect ion binding kinetics with resultant modulation of biochemical cascades relevant to the inflammatory stages of tissue repair.

High strength repetitive magnetic stimulation (rMS) has been found to relieve musculoskeletal pain. Specific diagnoses were painful shoulder with abnormal supraspinatus tendon, tennis elbow, ulnar compression syndrome, carpal tunnel syndrome, semilunar bone injury, traumatic amputation neuroma of the median nerve, persistent muscle spasm of the upper and lower back, inner hamstring tendinitis, patellofemoral arthrosis, osteochondral lesion of the heel and posterior tibial tendinitis. Patients receive rMS for 40 minutes. Mean pain intensity is 59% lower vs. 14% for controls. Patients with amputation neuroma and patellofemoral arthritis obtain no benefit. Those with upper back muscle spasms, rotator cuff injury and osteochondral heel lesions showed more than 85% decrease in pain, even after a single rMS session. Pain relief persists for several days. None have worsening of their pain.

Osteoarthritis (OA) affects about 40 million people in the USA. OA of the knee is a leading cause of disability in the elderly. Medical management is often ineffective and creates additional side-effect risks. The QRS has been in use for about 20 years in Europe. The QRS applied 8 min twice a day for 6 weeks improves knee function and walking ability significantly. Pain, general condition and well-being also improve. Medication use decreases and plasma fibrinogen decreases 14%, C-reactive protein (a sign of inflammation) drops 35% and the blood sedimentation rate 19%. The QRS has also been found effective in degenerative arthritis, pain syndrome and inflammatory joint disorders. Sleep disturbances often contribute to increased pain perception. The QRS has also been found to improve sleep. 68% report good/very good results. Even after one

year follow-up, 85% claim a continuing benefit in pain reduction. Medication consumption decreases from 39% at 8 weeks to 88% after 8 weeks.

Even strengths lower than the QRS may also treat knee pain in osteoarthritis. Treatment for eight 6-min sessions over a 2-wk period may give a 46% decrease in pain vs. an average 8% in the placebo group, sustained at the same level even two weeks after treatment.

A 50 Hz pulsed magnetic field sinusoidal, 0.035 Tesla field PEMF for 15 min for 15 treatment sessions improves hip arthritis pain in 86% of patients. Average mobility without pain improved markedly.

Post-traumatic Sudeck-Leriche syndrome (late stage reflex sympathetic dystrophy - RSD) is very painful pain and largely untreatable by other approaches. Ten 30-minute PEMF sessions of 50 Hz followed by a further 10 sessions at 100 Hz plus physiotherapy and medication reduced edema and pain at 10 days. There is no further improvement at 20 days.

Neuropathic pain syndrome (NPS) patients benefit from pulsed radiofrequency (PRF) treatment. Patients with severe left-sided sciatica and back pain, neuropathic pain in the anterior chest wall had been taking oral medications and had received repeated injections of local anesthetic agents and steroids with poor results. The patients treated with an invasive PRF applied to the related lumbar dorsal root ganglion for 2 minutes or the spinal roots of the thoracic T2-T4 dermatomes experience significant pain relief.

Even chronic musculoskeletal pain treated with MFs for only three days, once per day can eliminate and/or maintain chronic musculoskeletal pain.

A static magnetic foil placed in a molded insole for the relief of heel pain was used for 4 weeks to treat heel pain. 60% of patients in the treatment and sham groups reported improvement. There was no significant difference in the improvement on a foot function index. A molded insole alone was effective after 4 weeks. The magnetic foil offered no advantage over the plain insole, in this study. This study like others with low numbers of patients, may not have had a large enough sample. Placebo reactions in pain studies can be large and differences in benefit may be harder to detect. In addition, since magnetic foils produce fairly weak fields, placement against tissue becomes important, as does consideration of the depth into the body of the target lesion or tissue. Magnetic fields drop off in strength very rapidly from the surface.

Even small, battery-operated PEMF devices with very weak field strengths have been benefit musculoskeletal disorders. Because of the low strength used treatment at the site of pain may need to last between 11 to 132 days, between 2 times per week, 4 hours each or, if needed, continuous use. Use at night could be near the head, e.g., beneath the pillow, to facilitate sleep. Pain scale scores are significantly better in the majority of cases. Conditions that can be considered are arthritis, lupus erythematosus, chronic neck

pain, epicondylitis, femoropatellar degeneration, fracture of the lower leg and Sudeck's atrophy.

Musculoskeletal ailments may be also be treated solely using a broad band very low strength PEMF mattress-like device (QRS). Diagnoses may include intervertebral disc prolapse, spinal stenosis and osteoporosis. Only 20 sessions of 8 minutes, twice daily for two weeks help. Pain and forward bending ability improve. Longer term use would be expected to give even greater benefit.

240 patients treated with PEMFs in a conservative orthopedic practice had decreased pain, increased functionality and increased point pressure thresholds, disappearance of swelling and pathological skin coloration, less need for orthopedic devices and less reaction to changes in the weather. Treatments are daily for an hour. Conditions treated are: rheumatic illnesses, delayed healing process in bones and pseudo-arthritis, including those with infections, fractures, aseptic necrosis, loosened protheses, venous and arterial circulation, reflex sympathetic dystrophy all stages, osteo-chondritis dissecans, osteomyelitis and sprains and strains and bruises. The success rate approaches 80%. Even X-rays may show improvement. cartilage/bone tissue may reform, including the joint margin. About 60% of loosened hip protheses have subjective relief of pain and walk better, without a cane. Perthes' disease rarely completely reforms the articular head of the hip.

Summary

PEMFs of various kinds and strengths have been found to have good results in a wide array of painful conditions. There is little risk when compared to the potential invasiveness of other therapies and the risk of toxicity, addiction and complications from medications. Clearly more research is needed to elaborate mechanisms and optimal treatment parameters. Many studies that have been reported here have been controlled trials and many have been double blind placebo. Medical practitioners are becoming gradually aware of the potential of MFs to successfully treat or significantly benefit the myriad of problems presented to them.

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