

Application of AR technology in the treatment of Phantom Limb Pain

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Abstract. In recent years, with the continuous occurrence of accidents such as car accidents, wars, engineering accidents, natural disasters, tumors and vascular diseases, the number of patients with limb disability due to amputations or accidental injuries is also increasing. phantom limb pain (PLP), one of the main complications after amputation, has attracted increasing attention. Phantom limb pain, also known as phantom limb pain, refers to the subjective feeling that the amputated limb still exists, and is accompanied by varying degrees of pain, and the pain is mostly in the distal end of the amputated limb. Most phantom pain is combined with stump pain or phantom sensation. There are as many as 37 treatments for PLP, considering the high frequency of its occurrence and how much it affects patients. They can be broadly categorized as pharmacotherapy, physical therapy, and psychotherapy. Each of these therapies has its own drawbacks, which AR technology is well equipped to make up for.

Keywords: phantom limb pain;stump pain;phantom sensation; AR technology.

1. Clinical and psychological manifestations of phantom limb pain

Pain usually occurs within a week or weeks of amputation, but can occur months or years later. The site is mainly at the distal end of the amputated limb, such as the fingers and palm or the toe and bottom of the foot, where the limb has actually been amputated. The reported incidence is mostly 50%~80%(1, 2). Stump pain is a localized pain of the stump, which can be caused by local neuroma formation, ischemia, necrosis, adhesion, muscle spasm, stump malnutrition, and improper prosthetic limb. Phantom sensation refers to the phenomenon that after a limb or part of the body has been removed, the subjective feeling that the removed part is still present in the body.

The degree and nature of pain experienced by patients in amputated limbs varies. There are common knife cutting pain and needle-like pain, and in the later stage, most of them are throbbing pain, burning pain, needle-like pain, drilling pain or pressure, strong sense of stiffness, itching, etc., and even the sensation of nail embedding in the palm, accompanied by cold and heat changes in the skin of the stump and abnormal muscle tone at the end of the stump. It can be seen that pain paroxysms appear or worsen, quiet or nocturnal attacks, changes in mental state, weather changes, fatigue or other diseases can induce or aggravate pain. The duration of the pain can range from seconds to hours. The various sensations experienced before amputation may still be felt after amputation, and the sensation of the amputated limb is still present.

In the early stage after amputation, patients often cannot accept the reality of amputation, and the psychological trauma is heavy. Kern et al.(3) found that many phantom limb pain patients have decreased quality of life, affected work ability, and even lost work ability and reduced social ability. Moreover, in addition to pain, it is also manifested as depression, anxiety, lack of speech, insomnia, obsessive-compulsive disorder, loneliness, self-isolation, self-pity, loss of confidence, etc., which is called "amputation syndrome" (4).

Patients develop mild, transient phantom pain early after amputation, and most of these disappear on their own with appropriate prosthetics. There are also patients wearing prosthetic phantom limb pain is still frequent, the pain is getting worse, the duration is getting longer and longer, often accompanied by anxiety, depression, appetite loss and insomnia and other symptoms. The experience of pain before surgery is associated with phantom limb pain after surgery (5).

Phantom sensations can be induced by stimulating certain non-painful areas of the body surface after amputation, called "trigger zones." For example, in a person with a high limb amputation with

phantom pain, multiple sets of trigger areas are found on both sides, neck, upper chest, and upper back. Stimulate the trigger area, which can trigger phantom limb pain. The more severe the phantom pain, the greater the number of trigger zones. No trigger area was found in the waist, lower abdomen and lower limbs. The size of the trigger area can change over time, but there is always a clear correspondence between the phantom limbs. Phantom limb pain is often combined with stump pain, and simple phantom limb pain is rare. Sometimes patients have tenderness, such as the stump of the limb has obvious tenderness; Touching scar induration, proximal stump nerve stem is often tender. Phantom sensation usually diminishes or disappears with time; However, if phantom pain persists for more than 6 months, the likelihood of improving the prognosis is reduced(6).

2. Assessment of phantom limb pain

The occurrence time of phantom limb pain is different, and the incidence statistics and follow-up are difficult. In addition, phantom pain, phantom sensation and stump pain are interwoven, constituting a series of clinical symptoms, increasing the difficulty of diagnosis and treatment of the disease. Studies on phantom limb sensation reveal mirror neuron system and related behavioral manifestations. Phantom pain often occurs at the same time as stump pain and phantom sensation, which can easily be confused. The specific paresthesia of patients with neuropathic pain can be evaluated by the neuropathic pain Scale or neuropathic pain questionnaire (7), such as the McGill Pain Questionnaire, visual analog scale, digital scale and facial expression scale, and Disability Pain Index. Amputees have different mindsets about their disease and different tolerance to pain. Therefore, the mental state of patients at different periods should be evaluated when necessary, and targeted and individualized treatment plans should be formulated according to the results of pain testing and evaluation.

3. Possible mechanisms of phantom limb pain

Phantom pain is a type of neuropathic pain. So far, the understanding of its pathological mechanism has not been conclusive. Clinical trials have proved that phantom limb pain may be related to changes in various links of sensory afferent, such as changes in peripheral receptors, sensory afferent fibers, spinal cord conduction pathways, thalamus, and even cortex. Meanwhile, phantom limb pain is closely related to psychological factors of patients. It can be summarized in the following aspects:

3.1 Peripheral mechanism

Studies have shown that people with stump pain feel more significant phantom pain more often, and some studies have shown that phantom pain may be reduced after stump pain is relieved, but the relationship between the two is not clear. At present, it is believed that the chemical substances produced by cell injury at the nerve injury site after amputation, such as histamine and bradykinin, can stimulate nociceptive receptors and increase the frequency of pain afferent impulses. Abnormal discharge of nerve fibers or neuromas with peripheral nerve injury; Increased number and sensitivity of local alpha-norepinephrine receptors; The activation of phospholipase at the injury site converts arachidonic acid into prostaglandin and sensitises notional receptors. Afferent nerve ectopic discharge. These local changes also promote the upregulation of sodium ion channel proteins, which increases sodium ion conductivity and leads to phantom limb pain. Tapping a neuroma may increase nerve impulses in the afferent C fibers and may increase pain sensitivity. Although the limb no longer exists after the amputation, the nerve endings at the amputation site continue to send signals to the brain that make it think the limb is still there. The brain has a memory for pre-amputation pain, and signals from injured nerves are interpreted as pain.

3.2 Spinal cord mechanism

Dorsal root ganglion cells are altered after nerve resection, showing abnormal autonomic activity and increased sensitivity to mechanical and neurochemical stimulation. Therefore, it can be considered that the abnormal electrical activity of neuroma and dorsal root ganglion cell bodies is an important cause of phantom limb perception and pain. The neurons in the posterior horn of spinal cord that feel the nociceptive impulse are sensitized and excitability is increased, and they also respond to non-nociceptive stimuli. Peripheral nerve transection can result in substantial degeneration of afferent C fibers in the posterior horn II layer of the spinal cord, thus reducing the number of synapses in the posterior horn II layer of the spinal cord that normally respond to nociceptive stimuli and contact with secondary neurons. Subsequently, low-threshold A fibers, which should have entered the posterior horn of the spinal cord in layers III and IV, are introduced to the posterior horn of the spinal cord in layer II and form synaptic contact with the secondary neurons that are free to feel nociceptive pain. This input of information triggered by low threshold A fibers makes even simple contact cause pain(8).

4. Treatments for PLP

There are as many as 37 treatments for PLP, considering the high frequency of its occurrence and how much it affects patients. They can be broadly categorized as pharmacotherapy, physical therapy, and psychotherapy. Each of these therapies has its own drawbacks, which AR technology is well equipped to make up for(9).

Conventional medications for phantom limb pain include opioid analgesics, antidepressants, and anticonvulsants, but they all have their obvious shortcomings(10).

The opioid medication morphinesulphate MST, which Huse tested using his double-blind method, proved successful in reducing phantom limb discomfort without having a major impact on the participants' pain threshold. Somatosensory cortical changes were found in patients with pain alleviation, nevertheless, after 6–12 months of usage. There was no clear answer as to whether this pain reduction is genuine or if it is merely a short-term suppression that could eventually lead to more severe pain(11).

Antidepressants achieve relief of phantom limb pain by modulating neurotransmitters in the brain and are more effective in treating more severe phantom limb pain, but they can have side effects such as drowsiness, dry mouth, and blurred vision(12).

Similar to antidepressants, anticonvulsants also relieve PLP via altering the brain's neurotransmitters. Take Gabapentin as an illustration, it significantly reduces phantom limb pain and does not result in long-term side effects such as personality changes, but is prone to drug resistance.

Contrarily, AR technology has a superior level of security, doesn't impair the patient's subsequent normal life, and doesn't result in any unidentified perceptual abnormalities. In his 2014 research, Max Ortiz-Catalan saw a significant improvement in the patients' symptoms. Their daily lives had started to return to normal, and the fact that the patients continued to improve six months after the conclusion of the 12 treatment sessions provided additional evidence of the AR therapy's ongoing therapeutic impact.

Acupuncture, which originated in China and is now used all over the world, is a common physical therapy treatment for pain caused by phantom limbs. According to medical experts, it is often helpful, especially for limb pain and movement problems caused by blood and meridian blockages. According to reports, a 41-year-old woman who had lost her right lower leg in a car accident was able to regain it thanks to the large prick method, a form of acupuncture.

Acupuncture, however, continues to lag behind AR technology in terms of popularity and efficacy.

As a foreign therapy, acupuncture in traditional Chinese medicine has a complex system of 7 types of needles and 4 types of needle entry techniques, which few Chinese doctors, let alone foreign doctors, are able to fully grasp and apply correctly. The dual complexity of theoretical and practical

approaches has led to a slow diffusion of acupuncture, with many countries preferring traditional medicine or surgery to treat patients' pain.

The second issue is efficacy. Acupuncture patients exhibit a wide range of healing. Bradbrook's experiment involved treating three individuals with phantom limb discomfort with acupuncture. The outcomes showed that one patient, who underwent an amputation owing to a serious vehicle accident injury, had a bad outcome, whereas two other patients experienced large qi gains and noticeably lower pain levels. In light of this, Bradbrook came to the conclusion that acupuncture may only be helpful for patients who had simple trauma or non-traumatic amputations, and that it may be less helpful and not even useful for amputations brought on by severe, complicated trauma.

In comparison, AR technology is superior in both respects:

It has first attracted a lot of interest due to the variety of applications it has. When it comes to specific phantom limb pain treatments, a Google search for AR technology returns 3730000 results, a significant number higher than the 874000 results returned by a search for acupuncture. Even on specialist academic search engines like Google Scholar, the number of phrases linked to AR technology (21100) is still over twice as high as the number of terms related to acupuncture (11800).

The risk of poor efficacy due to inadequate theoretical understanding and likely rejection brought on by puncture is then considerably decreased by using AR technology to relieve pain through vision rather than physically touching the patient's limbs. As a result, it can handle more PLP patients. A 12-times study involving 14 amputees found that watching themselves use augmented reality to play games with their amputated hands significantly reduced their discomfort. Additionally, a virtual arm reduces the duration, frequency, and intensity of phantom limb pain in amputee patients by almost 50%, according to research published in the renowned medical magazine "Lancet".

If the first two are less effective than AR technology due to different treatment philosophies, then how about psychotherapy?

Consider mirror therapy (MT) as an illustration. It replicates an image of the activity from the healthy side to the damaged side using the idea of plane mirror imaging. The visual illusion leads to functional remodeling of the cortical areas on the patient's affected side of the brain, which relieves PLP by making the affected limb appear to be doing the same movement.

As seen from the descriptions, mirror therapy and AR therapy are similar in their therapeutic principles and consequently perform well in their efficacy. A large number of studies have proved that mirror image therapy can effectively promote the recovery of upper limb motor function in hemiplegic stroke.

In addition, mirror therapy still has a rich research history and is site-independent. First proposed in 1995 by Ramachandran and other scholars and applied in pain management for patients with phantom limb pain, it is suitable for both public medical institutions, such as large hospitals and community rehabilitation organizations, and private use.

However, the features of the mirror apparatus place a restriction on mirror therapy. Based on plane mirrors or combined with lenses, it places a strong emphasis on symmetry. It is challenging to evaluate the normalcy and uniformity of the mirror treatment training paradigm since there are so few training movements that may be employed to achieve symmetry.

AR technology, instead, solves the issue of symmetry-focus-limited training movements. By watching the severed limb move normally in the video, it enables patients to complete the stimulation of their brains.

Given that AR technology is more effective, has a shorter treatment cycle, and has less side effects than conventional therapies in treating PLP, its use in medicine gives patients with phantom limb pain fresh hope and more options. The use of AR as a representative of new technology graphically demonstrates how technology may alter people and the environment in which they live.

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