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EDITORIAL

The Future of Pain Medicine: Emerging Technologies, Treatments, and Education

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During the early days of chronic pain management, there was a reliance on the use of opioids with a significant increase in opioid prescriptions by physicians in the 1990s and early 2000s.[1] Opioids can and should be utilized to treat pain in the appropriate patient populations and situations, however, due to the initial consequences of the prior boom in opioid use to treat pain there has been resultant decrease in opioid prescription.[1] This decrease in opioid prescriptions and availability have inspired innovators in the field of pain medicine to develop new modalities and procedures that more effectively target a patient's pain generator. The vital task now with the abundance of newer technologies for chronic pain management is to properly educate the next generation of pain physicians on the benefits and risks of these technologies and more clearly define which therapies are evidence-based.

One such innovation being utilized to combat chronic pain is virtual reality (VR) which provides us with a treatment for chronic pain via modalities such as distraction, neural reprocessing, and mindfulness training.[2–4] The distraction element of VR functions by treating pain via reduction of the subjective sensation of pain by redirecting the user's attention away from the pain.[2] Although this modality has already been employed for treating acute and post-surgical pain, it has shown promising results in managing chronic pain conditions.[3,4] As a non-invasive and non-pharmacological approach, it may help tackle the complex challenges of chronic pain, offering a potential pathway to enhance patient outcomes and improve quality of life.[2] Given its high prevalence and significant public health impact, chronic low back pain is currently the most extensively studied chronic pain condition in the field of VR applications.[2] Current data show VR not only has a significant impact on alleviating chronic low back pain, with patients reporting reductions of 2.0 points on the NRS in some studies, but it can also impact secondary outcomes that have major impact on a patient's quality of life.[2,4] Furthermore, some VR technologies have demonstrated a comparable analgesic effect to opioid medications which is extraordinarily impactful as it is being shown to have efficacy without having significant side effects, medication interactions, and being available for patient use at home.[2] These findings highlight the potential of VR as a groundbreaking tool in the management of chronic pain, and innovators are working to integrate it into other modalities to increase the efficacy. Furthermore, via the use of augmented reality (AR), there is the possibility to have a real-time overlay over what the user experiences in the real world. Thus, patients, who otherwise may not be able to go to a physical appointment or live a considerable distance from a healthcare center can have a higher quality form of telehealth.[3] Lastly, there has been sparked interest in using VR to treat nociplastic pain, a type of pain that arises from altered nociception causing the activation of peripheral nociceptors, despite no clear evidence of actual or threatened tissue damage or evidence for disease or lesion of the somatosensory system causing pain. Through the use of VR-based interventions, there is evidence of neuroplastic changes in the sensory and motor regions of the brain resulting in adaptive

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cortical reorganization induced by consistent use of VR therapies.[5] VR may not only be considered a modality for gamers but may be a well-needed treatment for chronic pain patients.

A second innovation is wearable medical technology that can assist patients living with chronic pain. The documented willingness of chronic pain patients to use wearable medical technology for extended periods has sparked significant growth in this field.[6] Through wearables, particularly those taking advantage of existing of VR programs, one can enhance the use of VR and telemedicine by tracking a wide variety of factors ranging from vitals to complex physiological signals that may have a profound impact on patients' pain as well as their function.[6] By closely monitoring the data on applications built into wearable technology, one may be able to find new physiologic data that correlates with patients' pain. Beyond providing researchers and physicians with valuable information, wearables are already being shown to provide patients with secondary benefits. When chronic pain patients utilize a wearable medical technology, such as a smartphone or smartwatch that uses an integrated application to measure pain via a surrogate measure, these patients have been shown to have a significant decrease in depression.[6] Patients were also found to decrease the use of opioid medications.[6] Wearable medical technologies not only offer valuable insights for healthcare professionals but also provide significant therapeutic benefits for chronic pain patients, making it a promising tool in the management of pain and associated conditions.

Artificial intelligence (AI) has become another revolutionary innovation in the treatment of chronic pain. This emerging area technology makes use of computational algorithms to organize, predict, and/or influence future behaviors or outcomes.[7] Utilizing AI also can affect how we use VR and process wearable data as these programs could be trained to alter the VR environment in real time by having an AI avatar engage the users and processing wearable data to adjust said environments. Furthermore, via machine learning, data mining, and natural language processing, all of which takes advantage of AI, studies have shown an aptitude to improve our ability to effectively recognitive our patients' pain.[8] Beyond this, AI has even been shown to have improving capabilities to predict patient's pain.[8]

This predictive ability can be a powerful tool in the setting of neuromodulation. Neuromodulation is rapidly expanding modality that refers to the process of regulating or altering nerve activity by delivering electrical or pharmaceutical agents directly to a target area. While much of the underlying mechanism behind its treatment effect remains largely unknown, the gate control theory proposed by Melzack and Wall in the 1960s, likely plays a critical role in its efficacy.[9,10] By integrating AI into neuromodulation, data collection and monitoring phases of neuromodulation can be enhanced, allowing for opportunities to significantly improve outcomes for chronic pain patients.[11] This integration is paramount as there is higher patient satisfaction, improved pain control, and reduced caretaker burden amongst patients undergoing neuromodulation that are taking place in remote monitoring.[12] However, given the current state of AI technology requiring higher computing power and energy requirements, the ability to apply AI currently is limited in the setting of neuromodulation. One solution is utilizing the cloud to handle these complex operations while sending the data back to the cloud-connecting neuromodulation device with the hopes of one day freeing the user and setting the neuromodulation device on autopilot.[12] These future capabilities may then allow the device to adapt to the patient's pain and potentially predict pain.

Aside from taking advantage of new technology and the numerous novel medications in development such as sodium channel blockers, peptides, and cannabinoids, there has been a recent renewed interest in psychedelics as a method for treating pain.[13,14] Previous studies on the therapeutic benefits of psychedelics have largely focused on psychiatric conditions, as studies had demonstrated that psychedelic serotonergic agonists, such as psilocybin and lysergic acid diethylamide, can provide long-lasting benefits for refractory depression, end-of-life anxiety, and addiction when given in hallucinogenic doses alongside psychotherapy.[15–17] While the method in which psychedelics treat pain is not completely understood, the proposed mechanism involves serotonin 2A (5-HT_{2A}) receptor agonism resulting in "reset" of regions of functional connectivity (FC) in the brain that are crucial in many central neuropathic conditions.[15,18] Over the past 50 years there have been reports that have shown possible analgesic benefit of psychedelics in the treatment of cancer pain, phantom limb pain, and cluster headaches.[18,19] These preliminary studies have resulted in significant interest in research in the effect of psychedelics on chronic pain conditions. While this research is still developing, there have already been recent studies and case series that have shown promise in psychedelics being potentially effective therapy for difficult to treat conditions, such as fibromyalgia and neuropathic pain.[15,18] At this time further research is needed to better

understand the role psychedelics can have in treating chronic pain but early research shows promise in potentially being a future pain medication.

The current field of pain medicine exists in an incredible era such that we have other modalities, VR, wearable technology, AI, cloud-computing, and psychedelics, that may one day bring relief to hundreds of millions across the globe. These modalities may have a synergistic effect when integrated together; however, despite the wave of new modalities, educating the next generation will require a shift in the pain medicine education paradigm. Going forward, it will soon become vital for trainees to experience these modalities during training to have a comprehensive toolkit to treat their patients. With continued advancements at the recent accelerated pace, these innovative technologies may one day also be used to provide adaptive, novel ways to educate those entering and those currently in the field of pain medicine.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

CLR is a consultant for Augmend Health. GLB reported personal fees from Abbott and Stryker. MSc is a senior medical advisor for Apurano Pharma, outside the submitted work. TE has stock in Vanish Therapeutics. The authors report no other conflicts of interest in this work.

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