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REVIEW

A Review of Chronic Pain and Device Interventions: Benefits and Future Directions

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ABSTRACT

Chronic pain is a debilitating condition with a growing prevalence both in the USA and globally. The complex nature of this condition necessitates a multimodal approach to pain management that extends beyond the established pharmaceutical interventions currently employed. A variety of devices comprising both invasive and noninvasive approaches are available to patients, serving as adjuvants to existing regimens. The benefits of these interventions are notable for their lack of addiction potential, potential for patient autonomy regarding self-administration, minimal to no drug interaction, and overall relative safety. However, there remains a need for further research and more robust clinical trials to assess the true efficacy of these interventions and elucidate if there is an underlying physiological mechanism to their benefit in treating chronic pain or if their effect is predominantly placebo in nature. Regardless, the field of device-based intervention and treatment remains an evolving field with much promise for the future chronic pain management.

Keywords: Chronic pain; Spinal cord stimulator; Intrathecal and epidural drug delivery systems; Transcutaneous electrical nerve stimulation; Dorsal root ganglion stimulators; Peripheral nerve stimulation; Noninvasive neuromodulation; Mobile applications; Virtual reality

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Key Summary Points

Chronic pain is a complex condition with increasing prevalence and significant impact on quality of life for patients necessitating multimodal approaches to pain management.

A variety established and novel invasive and noninvasive approaches besides pharmaceuticals exist for patients suffering from chronic pain.

Options for pharmaceutical adjuncts range from clinic-based interventions to self-administered, noninvasive devices that provide patients with autonomy and control over their chronic pain condition.

The nonpharmaceutical options for treatment of chronic pain continue to grow and evolve with novel technologies and offer patients low-risk alternatives with minimal to no risk for drug–drug interactions.

Despite the promise of these adjuncts to pharmaceutical intervention for chronic pain, a need for large-scale clinical trials and further research remains to elucidate the true efficacy of these interventions.

INTRODUCTION

Chronic pain is a complex problem that places a significant burden on the patients affected by it. In contrast to acute pain, which provides a survival benefit, chronic pain continues to persist after healing from an injury or disease has taken place, or pain that occurs in the absence of prior tissue damage. Although commonly a product of injury or disease, it is imperative to consider chronic pain as a unique and separate condition given the variety of treatment modalities available to clinicians and patients [1, 2].

The prevalence of pain both worldwide and in the USA demonstrates the need for myriad approaches to chronic pain management. The National Health Interview Survey data indicate a prevalence in the USA of approximately 20.5% (50.2 million) American adults being affected by chronic pain [3, 4]. Globally, approximately 1.9 billion people display common symptoms of chronic pain, such as tension-type headaches [2]. The allostatic load hypothesis postulates that individuals who endure persistent daily exposure to poor socioeconomic conditions are predisposed to the development of numerous diseases, including chronic pain, due to the elevation and accumulation of stress hormones such as cortisol. In essence, a steady-state, sympathetic fight-or-flight state of existence results in an accumulated stress on the body that eventually manifests in a variety of disease states. Furthermore, patients with lower socioeconomic status (SES) were found to have greater disability secondary to chronic pain and experience more intense pain compared with individuals from higher SES classes [5–7].

The complex nature of chronic pain necessitates a multimodal approach to its management, with therapies designed to target various aspects of its biopsychosocial composition in a stepwise escalating manner. Initial interventions are comprised of oral analgesics, ranging from nonsteroidal antiinflammatories (NSAIDs) to weak and strong opioids. Topical formulations of both opioids and nonopioids are viable alternatives, especially given their improved safety profile in comparison to the oral formulations [8–10]. Additionally, the aforementioned medications can be supplemented with adjuvant therapies designed to address neuropathic pain in particular: antiepileptics and antidepressant therapies. Furthermore, antidepressants serve a multi-pronged approach given their primary function of treating the commonly associated comorbidities of depression and insomnia with chronic pain [11]. Patients with persistent or progressive pain despite oral and transdermal analgesic interventions are often candidates for interventional management. These therapies include nerve blocks, denervation procedures, implantable devices such as infusions pumps and neurostimulators, and transcutaneous electrical nerve stimulation (TENS). New approaches to chronic pain management include mobile applications and virtual reality (VR), both of which have shown promise in meta-analyses as potential primary interventions given their safety profiles [12, 13].

METHODS

A literature review was conducted using keyword searches of the PubMed database, specifically focusing on chronic pain, spinal cord stimulators, intrathecal and epidural drug delivery systems, transcutaneous electrical nerve stimulation, dorsal root ganglion stimulators, peripheral nerve stimulation, noninvasive neuromodulation, mobile applications, and virtual reality. Specifically, the intention was to do a narrative review educating on the aforementioned devices and not a comprehensive systematic review. While no inclusion or exclusion criteria for date of publication were established, an emphasis on more recent literature was used during review of the current literature. Eighty-one resources were selected for the literature review, with approximately 30 literature sources being discarded due to date of publication and updated findings in the literature or lack of relevance to the topic. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

RESULTS

Spinal Cord Stimulator

A spinal cord stimulator (SCS) is a device that leverages the principles of neuromodulation of pain pathways to provide pain relief through electrical stimulation of the adjacent dorsal column pathways when placed in the epidural space, usually with radiographic guidance. As theories of pain control have moved beyond gate control theory, the mechanism of SCS pain modulation has likewise developed, with SCS modulation thought to affect the descending antinociceptive system (DAS) and local gamma aminobutyric acid (GABA)-ergic, cholinergic, and serotonergic neurons affecting segmental and supraspinal neurophysiology and central and peripheral neuroinflammation [14, 15]. After implantation of the electrical stimulation leads, they are attached to a battery pack and stimulation generator that are usually placed in a subcutaneous pocket. While patients with intractable focal neuropathic pain, such as those with polyneuropathy or phantom limb pain may benefit from this intervention, the most evidence for use of these stimulators is currently regarding patients who have been labeled as suffering persistent spinal pain syndrome (PSPS) type 2. PSPS type 2 represents an unfortunate category of patients who have persistent low back pain following back surgery. The efficacy of SCS in PSPS type 2 patients is underpinned by two studies, which together found that SCS was more effective than both reoperation or medication management with the outcome being a significant (> 50%) reduction in pain. In the first, 50 patients were followed and SCS was found to be more effective than reoperation in relieving pain for lumbosacral radicular pain in PSPS type 2, with the primary measure being > 50% pain relief after the procedure [16]. The second study showed that patients with persistent radicular pain after surgery for disc herniation had better pain control with SCS versus medication management [17]. These two studies together suggest that in PSPS type 2, patients have a higher likelihood of significant (> 50%) pain relief with SCS versus reoperation or continued medication management. However, it is important to mention that along with the increased likelihood of significant pain relief, about 25% of patients have been found to have complications such as wound infection or breakdown, lead or electrode problems, or battery pocket complications [16, 17]. There is no high or moderate quality evidence for the use of SCS in patients with low back pain without previous back surgery according to the recommendations from the American Pain Society [18]. As such, the use of SCS in PSPS type 2 should be undertaken following an appropriate informed consent and shared decision-making process regarding the likelihood of significant pain relief balanced with the risks of further complications and lack of significant relief.

Intrathecal and Epidural Drug Delivery Systems

Intrathecal and epidural drug delivery systems are primarily employed in patients with neuropathic chronic pain, often secondary to spinal cord injury. This method relies on placement using radiographic guidance and the implantation of a pump/reservoir in a subcutaneous pocket. There is evidence for use of these drug delivery systems primarily in the administration of baclofen, morphine, and clonidine for modulation of spasticity, chronic intractable pain, and the autonomic nervous system, respectively [19–21]. Baclofen is a centrally acting skeletal muscle relaxant, which is a structural analog of GABA, used to reduce spasticity in patients with spinal cord injury. When given intrathecally, it allows for much smaller doses than when given systemically, maximizing the benefits for mobility while minimizing the drowsiness and neurological side effects that come with systemic administration [20, 22]. Intrathecal or epidural morphine treatments benefit from route of administration in much the same way, allowing for modulation of central pain regions at lower doses than systemic treatment (likely secondary to more direct access to the substantia gelatinosa) while minimizing potential side effects and the risk of central respiratory depression [23]. This has been particularly helpful in chronic pain from cancer, and interventional pain management has a role to play in the comprehensive treatment of intractable cancer pain [24]. Finally, the use of clonidine as an adjunct to local anesthetics, morphine, and baclofen has been studied with regards to the analgesic effects of both its α-2 agonism and recent research suggesting that they may have a role in inhibiting allodynic pain signaling through inhibition of proinflammatory cytokines [25, 26]. Clonidine has also been found to be effective for patients with complex regional pain syndrome (CRPS) [27].

Dorsal Root Ganglion Stimulator

Dorsal root ganglion stimulators are devices similar to SCS, but focus on the first-order sensory neurons whose cell bodies sit in the dorsal root ganglion (DRG) and project from the distal nociceptors to the spinal cord and central nervous system (CNS). The DRG is a good target for stimulation because of its position in the epidural space bathed in cerebral spinal fluid (CSF), as well as the ability to spatially target chronic pain [28]. In fact, a systematic review of current literature in 2019 suggested that DRG stimulation has significant efficacy in the treatment of CRPS types I and II, as well as for patients who have focal neuropathic pain with an identified pathology. In fact, DRG stimulation was agreed upon to be superior to tonic SCS for focal pain secondary to CRPS I or II in the lower extremities [29, 30]. Another prospective study on patients with intractable chronic pain of the trunk or lower limbs secondary to PSPS type 2, CRPS, or peripheral nerve injury found that DRG stimulators provided significant (> 50%) pain relief in 49% of patients, while reducing the primary area of pain in these patients [31].

Transcutaneous Electrical Nerve Stimulation

Transcutaneous electrical nerve stimulation (TENS) is a hand-held device that delivers noninvasive low-voltage electrical currents through adhesive electrodes that are applied to patients' skin. The amplitude, frequency, duration, and pattern of the electrical currents can be adjusted to provide analgesia specific to a patient's needs. The exact mechanism of analgesia is likely multifactorial in nature and involves multiple aspects of the pain-signaling pathway. Specifically, TENS results in activation of large diameter afferent fibers that subsequently cause activation of descending inhibitory systems in the central nervous system functions to modulate the perception of noxious stimuli. This mechanism relies on the gate control theory of pain modulation: activation of lower-threshold potential for activation mechanoreceptor afferents will inhibit or downregulate ascending signals from higher-threshold nociceptive afferents [32–35]. This proposed mechanism was supported in studies where the periaqueductal gray (PAG), rostral ventromedial medulla (RVM), and spinal cord were blocked, resulting in decreased efficacy of TENS analgesic effects [36]. Peripherally, TENS has been shown to reduce substance P release, a proinflammatory molecule, as well as modulation of alpha-2a receptors [37, 38].

The intensity of stimulation is therefore a critical factor in optimizing efficacy, regardless of frequency of application. Intensity needs to produce a strong, nonpainful sensation to stimulate mechanoreceptor afferents with subsequent titration during treatment to maintain an adequate level of activation for 30 min. As previously mentioned, TENS has mechanisms to produce hypoalgesia or analgesia through peripheral means described as extra-segmental analgesia: decreased inflammation-induced dorsal horn neuron sensitization, altered levels of inhibitory neurotransmitters such as gamma-aminobutyric acid and glycine, and modulation of the activity of cells that support and surround neurons in the spinal cord. These extra-segmental effects are targeted when using acupuncture-like TENS therapy [32, 35].

One of the most significant advantages of TENS in chronic pain management is the autonomy patients derive with the device, and the minimal adverse effects and abuse potential. Furthermore, it provides an additional adjuvant to a patient's analgesic regimen without concern of polypharmacy or unwanted drug interactions. Multiple randomized control trials (RCTs) have shown benefit in the management of both acute and chronic pain, including arthritis, chronic low back pain, fibromyalgia, myopathy, and neuropathic pain [32, 33, 39–41]. However, the quality of these RCTs remains in question. Several meta-analyses have been conducted to assess the quality of data regarding the efficacy of TENS in chronic pain management and were relatively consistent in their findings. There is a plethora of poorly powered trials; however, the majority favors a benefit from TENS intervention when compared with a lack of benefit or adverse effects [33, 42, 43].

Despite the benefits, there are limitations to this noninvasive intervention. The electrodes must be placed on healthy skin directly over the painful area for best results. Additionally, while the pulse amplitude is a key factor on how patients will respond to TENS due to the relationship to fiber recruitment, the effects of other modifiable aspects are based on poor research, failing to pinpoint the sole influencer. Therefore, a trial-and-error approach is required to establish the most efficacious device settings, which may be a hindrance to patient compliance. Progression of the chronic pain condition may also limit the analgesic effects over time, necessitating additional manipulation of the amplitude, frequency, duration, and pattern of the electrical currents. The limitations of TENS grow evident when used as the only treatment for moderate-to-high acute pain, thus supporting its role as an adjuvant in a multimodal analgesic plan [32, 34, 44].

Peripheral Nerve Stimulation

Peripheral nerve stimulators (PNS) are approved for use in intractable pain of peripheral nerve origin. This allows for targeted pain relief without disruption of the central nervous system and without violating the dural sac. The peripheral, noninvasive approach reduces the risk profile of stimulator placement, but also confines its benefits to one or two localized peripheral nerve distributions [45]. However, the lack of surgical intervention results in a more attractive option in cases where anticoagulation status or other limitations prevent placement of a more centrally acting nerve stimulator. The use of PNS in chronic pain treatment is on the rise, with much of the literature regarding its use and possible applications occurring within the past few years. It has been shown to be effective in the treatment of CRPS types I and II, as a retrospective chart review at the Cleveland Clinic showed a 20% reduction in opioid use 12 months after placement, as well as improved pain scores in this study and other prospective studies [46, 47]. It is also effective in the treatment of trigeminal neuropathic pain and phantom limb pain [48, 49]. A systematic review of the literature shows that the strongest case for PNS use is in chronic pain from refractory peripheral nerve injury, followed by use for pelvic pain and cluster headaches [50]. However, given the exciting future ahead for the use of PNS, future applications extend to essentially any named nerve as long as basic tenets of safe implantation are followed. The most significant risks associated with PNS are those of lead migration and erosion (given proximity to neurovascular bundles and generally more movement than with axial SCS leads), and issues such as lead fracture and infection. As such, it represents a relatively safe and reliable option for the treatment of refractory chronic pain in limited nerve distributions. A promising new horizon for PNS exists when looking at both the increase in purpose-built systems for implantation, as well as examinations of possible mechanisms by which PNS may influence CNS remodeling and potentially lead to prolonged improvement of pain beyond the period of stimulation [51, 52].

Noninvasive Neuromodulation

Neuromodulation involves the alteration of nerve activity, either peripherally or centrally, via a targeted stimulus that can be range from noninvasive to surgical modalities. Noninvasive neuromodulation in particular is an appealing method of chronic pain management given its nonaddictive qualities and safety profile in comparison to pharmacologic and invasive interventions. Currently, there are three forms available to patients: transcranial magnetic stimulation (TMS), transcranial current stimulation (TCS), and transcranial focused ultrasound (tFUS).

The mechanism of action of TMS remains unclear, although it is likely multifactorial in nature, with several studies showing a potential for individualized responses to the stimulation [53]. One proposed mechanism; however, is that TMS of the motor cortex restores inhibitory processes that are likely impaired in chronic pain conditions [54]. Additionally, cortical stimulation may result in enhanced endogenous opioid secretion in nociceptive modulation brain regions such as the periaqueductal gray [55, 56]. TMS has been shown to be efficacious in the treatment of chronic neuropathic pain with evidence of prolonged analgesic effects after multiple sessions [57–59]. Regarding other forms of chronic pain, there remains limited evidence but some studies show promise for condition such as CRPS and fibromyalgia [60, 61].

TCS relies on direct current stimulation of the cortex to either reduce (cathodal) or increase (anodal) excitability of neurons directly under the area of the scalp electrodes [62]. In a similar mechanism to TMS, this stimulation of modulates the inhibitory mechanisms the cortex to reduce overactivity in thalamic nuclei and activate descending pain control mechanisms [63, 64]. Multiple clinical trials have been conducted with subsequent meta-analyses showing moderate analgesic effects in a variety of chronic pain conditions; however, clinical recommendations exist only for fibromyalgia and lower-limb pain [53, 65].

Unlike TMS and TCS, which suffer from tissue attenuation and lack of spatial precision, tFUS is an emerging technology that can be readily adjusted to target specific cortical regions with greater fidelity. The pulsed mechanical energy from the ultrasound transducer can be adjusted to induce excitation or inhibition as necessary to elicit the desired analgesic effects. The exact mechanism of tFUS remains unclear at this time and additional studies are necessary to elucidate the chronic pain conditions that would benefit most from this growing technology [65–67].

Mobile Applications and Virtual Reality

The use of mobile phone applications in managing chronic pain provides an alternative to more invasive interventions such as implantable devices or TENS. Furthermore, given how common access to mobile phones has become, these applications offer patients an out-of-clinic modality that is readily available to facilitate a multimodal approach to their chronic pain symptoms. Several meta-analyses have examined the efficacy of various applications and were notable for improvements in patients' perceptions of their pain in addition to quality of life measures [13, 68]. Additional benefits are based on the autonomy patients exercise in utilizing these interventions, creating more ownership over their pain management in an effort to reduce relapse rates [69].

The context of mobile applications span a broad spectrum, ranging from instructions on self-acupressure to music intervention and artificial intelligence, to chat forums moderated by experts in pain management [70–72]. However, despite the myriad of options available to patients and the noted improvement in pain scores, care must be exercised due to the lack of scientific validation and low-quality consensus guidelines that are used in developing these applications. Furthermore, the implementation of self-management support and behavior-modifying features is often lacking, raising the question of long-term pain improvement with cessation of use [69, 73, 74]. Regardless, these interventions offer a promising adjunct to current pain management regimens, especially when careful consideration by the physician and patient is undertaken to ensure high-quality and well-developed applications are used.

Another novel and evolving noninvasive patient-autonomous intervention utilizes virtual reality (VR) to create an artificial three-dimensional (3D) environment in which patients can interact via an avatar. A head-mounted display and various head and hand-held sensors allow for the perception of movement within the simulated environment. The primary mechanism of analgesia provided by VR is through manipulation of the neuromatrix theory of pain. Specifically, pain is a multidimensional experience influenced by cognition, sensation, and affect that can be attenuated with distraction [75–77]. The impact of distraction analgesia can be seen in functional magnetic resonance imaging of specific pain-related regions in the brain during VR distraction, with noted decreased activity in those regions [78]. This method of analgesia is especially potent in the acute pain setting as it has been implemented in pediatrics during venipuncture and other painful procedures [77, 79]. However, the pathophysiology of chronic pain is unique from acute pain and raises the question of the efficacy of VR in distraction analgesia and neuromodulation in this particular patient population.

Several meta analyses have analyzed the literature and found evidence of significant improvements in pain and quality of life (QoL) scores [12, 80–82]. In a prospective study conducted by Alemanno et al., the use of VR in reducing chronic low back pain was reviewed, focusing on pain and QoL scores in addition to neuropsychological and functional outcomes. Significant decreases in pain scores were noted for patients in addition to improvements in QoL scores. Although less profound, cognitive functions were also improved from baseline assessments. In particular, this study focused on the hypothesis of neuromodulation and body perception correction: specifically, patients with chronic low back pain often have poor perceptions of their functional abilities and somatic dis-perception, likely secondary to reorganization of the primary somatosensory cortex [77, 83–85]. Through multiple training sessions, participants showed enhanced movement reproducibility, lending support to the hypothesis of improving body perception with VR. Furthermore, all patients completed the study without any dropouts, in line with previous reports showing VR training to be a pleasant experience that is well tolerated by chronic pain patient populations [86].

Despite the significant benefits of VR training in improving pain and QoL scores in chronic pain patients, there remains a significant gap regarding the long-term effects of these interventions. A small study of six women with fibromyalgia conducted by Botella et al. showed improvement in functional status at 6 months post VR training; however, the small power of this study and lack of evidence in other forms of chronic pain necessitates a need for further investigation to elucidate whether there is long-term neuromodulation of specific brain regions [87]. Regardless, the decreasing cost of VR and relative accessibility should not preclude the implementation of this noninvasive therapy in a multimodality approach to management of chronic pain.

DISCUSSION

Chronic pain has a complex nature affecting multiple aspects of patient well-being that necessitates multiple avenues of management, ranging from oral analgesics to invasive interventions and more novel techniques such as mobile apps or VR. As outlined in the neuromatrix theory of pain developed by Melzack, management of chronic pain requires a multimodal approach to address the various factors that influence a patient's experience. Therefore, implementing a single treatment modality will likely create deficits that impede the ability to improve a patient's experience with chronic pain. Novel devices and approaches continue to become critical to devise more efficacious regimens to combat the ever-increasing burden of chronic pain that now affects more than one in five Americans.

Continued advances in chronic pain management are evident in the variety of devices available to physicians and their patients. Implantable devices comprise a wide variety of therapeutic modalities targeted to specific regions of the pain pathway. Spinal cord stimulators have been shown to provide significant reductions in pain in several studies; however, their efficacy has only been studied in a small subset of the various types of chronic pain, most notably PSPS type 2. This deficit of evidence provides an opportunity for future studies to assess the efficacy of SCS in the management of a variety of chronic pain types. DRG stimulators are an alternative to SCS in particular subsets of the chronic pain population, specifically those with CRPS. DRG stimulators were shown to have superior efficacy when compared with tonic SCS. Of note, however, is the important consideration that these invasive procedures are not without their own risk of complications and potential for device failure.

Intrathecal and epidural drug delivery systems have also been shown to provide relief of chronic pain to a greater variety of chronic pain than noted with SCS. Utilizing a variety of drugs such as baclofen, morphine, and clonidine to alleviate spasticity, chronic intractable pain, and the autonomic nervous system, respectively, these delivery systems can be tailored to the specific needs of each patient. A unique benefit of these systems is the route of administration limits the well-documented adverse effects of the aforementioned drugs due to the smaller doses required, thus limiting systemic absorption. Again, as noted with SCS and DRG stimulators, there are complications that must be considered with these devices in addition to certain preexisting conditions or prior spinal surgeries that would preclude patients from being potential recipients.

In contrast to the above devices, which are notable for their invasive nature and subsequent associated risks, TENS, noninvasive neuromodulation, mobile applications, and VR offer unique modalities of intervention with significant benefits rooted in their relative ease of access and minimal-to-nonexistent adverse effects. TENS devices rely on the gate control theory of pain modulation by providing nonpainful stimulation over the painful area to downregulate or inhibit afferent nociceptive signals in addition to extra-segmental release of endorphins and inhibitory neurotransmitters. The notable benefits of these devices are patient autonomy, ease of use, and their lack of abuse potential and adverse interactions with analgesic drugs. However, the relatively short-term effect and habituation to the stimulation requires more frequent application to obtain similar effects with prolonged use. Noninvasive neuromodulation techniques function through multiple mechanisms including upregulation of inhibitory processes and increased endogenous opioid release to produce analgesia. While TCS and TMS have been shown to be efficacious in a variety of chronic pain conditions, they lack the precision, depth of penetration, and modifiability that tFUS provides. However, given the relatively novel technique of tFUS and need for understanding parameter manipulation with excitatory and inhibitory pulses, further research is required to allow this modality to become a more common tool used in chronic pain management. Mobile applications comprise a broad spectrum of interventions designed to address particular aspects of chronic pain that can be selected to best suit a patient's needs and lifestyle. However, the limitation with these applications is their lack of high-quality consensus guidelines and scientific literature being used to develop them. This places an additional burden on physicians and care teams to ensure due diligence in selecting a mobile application to serve as an adjunct in a management plan, while raising the question of the long-term efficacy of these interventions. Specifically, the notable deficits in this area of chronic pain management necessitates the need for more a more rigorous process of developing and creating these applications to ensure their foundation in sound science and well-refuted consensus guidelines. VR, in contrast, relies on manipulating the neuromatrix theory of pain through distraction analgesia and body perception training. Studied in a variety of chronic pain conditions with notable success in patients with chronic low back pain, VR holds promise as an adjuvant with some evidence of long-term impact in particular populations, such as those affected with fibromyalgia. Additionally, the multimodal mechanism by which VR works to improve chronic pain creates an opportunity for further research to better understand the underlying physiology, in addition to implanting this adjuvant in previously untested chronic pain groups. Therefore, despite their drawbacks, mobile applications and VR provide a low-cost and low-risk adjuvant to more invasive or high-risk interventions.

CONCLUSIONS

The field of chronic pain management continues to evolve to address the need of this diverse patient population, as noted with the variety of treatment modalities above. This growth is a critical evolution given the complex nature of chronic pain and the myriad ways in which it manifests. However, despite these advancements in alternatives to oral analgesics such as opioids, there clearly remains a distinct need for persistent innovation in conjunction with rigorous research and development processes that involve all affected parties. Each device would benefit from a large systematic review to provide a more robust compilation of current information and data in addition to high-powered clinical trials and prospective studies to determine the true efficacy of these interventions and provide both clinicians and patients more clarity when considering the options available to them.

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Compliance with ethics guidelines. This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

Data availability. Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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