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The virtual peripheral nerve academy: education for the identification and treatment of peripheral nerve disorders

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Abstract

Millions of people around the globe suffer peripheral nerve injuries caused by trauma and medical disorders. However, medical school curricula are profoundly deficient in peripheral nerve education. This lack of knowledge within the healthcare profession may cause inadequate patient care. We developed the Virtual Peripheral Nerve Academy (VPNA) as a reusable virtual learning environment to provide medical students with detailed education on the peripheral nervous system (PNS). Students are introduced to the PNS through virtual 3D rendering of the human body, wherein they visualize individual nerves through dissection and observe normal motor and sensory function associated with each nerve. PNS structures that are absent from traditional texts are included in this visualization, ranging from the innervation of joints to the normal anatomic variation required for differential diagnosis of pain after an injury. Detailed modules on peripheral nerve disorders allow students to observe pathophysiological mechanisms, associated symptomatology, and appropriate treatments. Students are briefed on a patient clinical case, then interact with a patient avatar to learn the appropriate diagnostics, including physical exam maneuvers and electrodiagnostic testing. Interactive modules on peripheral nerve surgeries detail surgical techniques. The VPNA data and analytics dashboards allow medical students and course instructors to assess skill improvement and identify specific learning needs. The built-in learner management system and availability on both computer-based and virtual reality platforms facilitate integration into any existing medical school curricula. Ultimately, this immersive technology enables every medical student to learn about the peripheral nervous system and gain competency in treating real-life nerve pathologies.

Keywords: Virtual reality, peripheral nervous system, nerve, surgical education, medical education, simulation, plastic surgery

INTRODUCTION

The problem in healthcare

Peripheral nerve injuries (PNI) currently affect more than one million people worldwide, and the occurrence of trauma-induced PNI is steadily on the rise[1,2]. In addition to trauma-based PNI, disease-induced peripheral nerve disorders such as diabetic neuropathy are increasingly common with the rising prevalence of obesity and diabetes[3-5]. Over half of people with diabetic neuropathy in the United States present with upper and lower extremity nerve compressions[6]. Additionally, iatrogenic injuries frequently occur through surgical procedures, such as hernia repair[7-9], total knee replacement[10], and episiotomy[11], with many patients reporting chronic pain due to neuromas of surgically transected nerves. These injuries are notoriously devastating and life-altering as patients can face severe lifelong disabilities, including sensory loss, motor loss, and neuropathic pain[2,12-14]. Despite advancements in microsurgical techniques and basic and translational research, traditional treatments for nerve repair continue to have unsatisfactory clinical outcomes[2,13]. Among the many factors that influence peripheral nerve injury prognosis - including age and co-morbidities - the amount of time that elapses prior to end-organ reinnervation is perhaps the most consequential[13-17]. The importance of time is evidenced by the poor outcomes that tend to occur with proximal nerve injuries and delayed repairs. Therefore, education of medical students about the urgency of injury identification and referral to a peripheral nerve surgeon in a timely manner is most important.

Patients are faced with numerous barriers to care, including a lack of awareness of the signs and symptoms of common nerve injuries[18]. Furthermore, upon reaching a diagnosis, patients face barriers in finding a surgeon to care for their injury[19]. In 2017, over 40% of counties in the U.S. had zero surgeons per 100,000 population[20]. Additionally, access to surgeons trained in peripheral nerves, such as neurosurgeons, plastic surgeons, and hand surgeons, is even more limited, and consequently, injured patients may suffer from chronic pain and misdiagnoses.

The problem in medical education

Inaccessibility to peripheral nerve surgery is compounded by the lack of peripheral nerve training within the medical education system; much of the nervous system curriculum content focuses on the central nervous system and special senses. Medical students typically only gain brief exposure to the peripheral nervous system (PNS) through anatomy dissections and elective clerkships, despite the wide-stretched reach of this field. Consequently, this lack of knowledge leads to a gap in clinical skills related to gathering relevant, patient-centered, hypothesis-driven history, and physical examination data in the clinical setting. Therefore, it is imperative that medical students gain a thorough knowledge of how to identify and treat peripheral nerve disorders. For example, a simple clinical physical examination technique may be taught for the upper extremity carpal tunnel syndrome, but seems never to be taught for the nerve compression at the medial ankle, the tarsal tunnel syndrome, for which a positive Tinel sign has an 80% positive predictive value of successful nerve decompression[21].

Virtual reality in medical education

Virtual reality (VR)-based education is a promising avenue to not only integrate peripheral nerve system-focused content into medical school curricula, but also promote sustained knowledge. Educational VR technology provides a powerful environment for meaningful learning, enhances retention of existing curriculum, and encourages active participation over passive lecture experiences[22]. The use of VR technology within medical education has repeatedly been found to improve learning experiences and performance on examinations, and increase student confidence in their skills[23-26]. For example, VR-based anatomical education has been repeatedly found to improve examination performance over traditional prosection-based learning[26]. Given the multitude of benefits demonstrated by VR-based education, we sought to develop a VR rather than lecture-based curriculum on the peripheral nervous system to provide medical students with a reusable virtual learning environment. Additionally, as a study by Bartlett *et al.* found that the use of surgical VR simulations made surgical residency more appealing to students[27], we hope integrating this content into medical schools will encourage medical students to explore and ultimately pursue nerve surgery-related fields. We partnered with BioDigital Systems LLC to create an immersive, user-friendly peripheral nerve education virtual reality platform dubbed the "Virtual Peripheral Nerve Academy (VPNA)," which enables virtually any healthcare student or provider to easily learn about the peripheral nervous system and gain competency in treating real-life nerve pathologies. BioDigital Systems, LLC has a history of successful collaborations in healthcare education, including anatomical modules at the Johns Hopkins School of Nursing and surgical simulations with the New York University Langone Medical Center Department of Reconstructive Plastic Surgery[28-31]. Studies have found that the use of VR modules based on the BioDigital platform significantly improves knowledge of the procedure and increases trainee confidence[29,30]. Herein, we will discuss how VPNA is being developed at the Johns Hopkins School of Medicine.

THE VIRTUAL PERIPHERAL NERVE ACADEMY

General description

VPNA is an immersive, reusable virtual learning platform to provide medical students with a comprehensive education on peripheral nerve disorders and associated treatment. The VPNA curriculum is module-based and uses a variety of media, including still and animated graphics, motion video, and text. The VPNA is designed to be entirely virtual and can be integrated into existing medical school curricula led by experienced practitioners.

Trainees are first introduced to the VPNA historical timeline, which denotes significant figures like Santiago Ramon y Cajal of Spain (Nobel Prize, 1906), for his work on neuroanatomy, and Hanno Millesi of Germany, for his introduction of interfascicular interposition nerve grafting (1974), and Rita Levi-Montalcini of Italy (Nobel Prize 1986), for her discovery of nerve growth factor. This introduction serves both to set the foundation for the basics of the peripheral nervous system as well as the concepts that drive modern treatments.

After completing the introduction, trainees first learn about the components and inner workings of nerves at a cellular level. They can view the processes underlying normal synaptic transmission as well as the pathophysiology of nerve disorders and injury [Figure 1]. Trainees then learn how to classify nerve injuries into the Seddon and Sunderland classifications related to the degree of disruption of the neural structure.

Trainees then explore the nerves within the human body through a virtual rendering and can dissect layer by layer to locate individual nerves and branches [Figure 2]. Natural variations in nerve location are described. Users can observe normal motor function and sensory innervation through a physical exam with

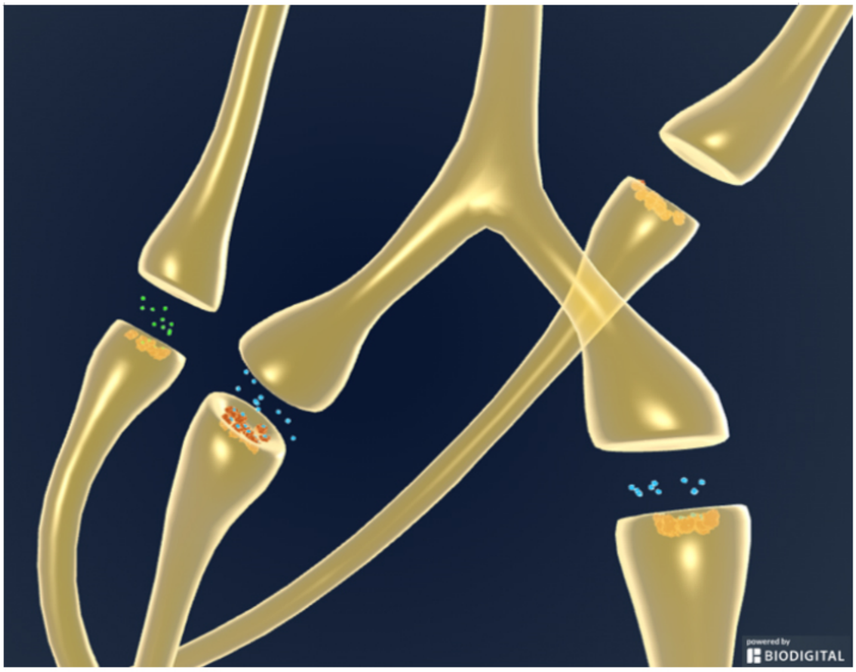

Figure 1. Modules on the cellular and molecular mechanisms of nerves take a focused look at normal neurotransmitter activity, as seen here, and pathophysiological processes. Module captured with permission from BioDigital.

an avatar and are quizzed at the end of the modules.

Target audience-appropriate experiences provide detailed, game-based learning on peripheral nerve disorders and appropriate treatment. Over 25 modules focus on individual nerve disorders such as brachial plexus compression/injury, facial pain and headache, facial palsy, joint denervation, and pelvic pain of neural origin. In addition, trainees can learn about peripheral neuropathy due to diabetes, leprosy, or chemotherapy. Trainees are briefed on a patient case and then interact with a patient avatar to learn the appropriate diagnostics - including physical exam maneuvers and electrodiagnostic testing - to diagnose and treat the patient [Figure 3]. Trainees gain competency in how to medically treat nerve injuries and learn when surgical intervention is necessary. Surgical intervention modules demonstrate the principles of nerve decompression, nerve repair, nerve reconstruction, and neuroma treatment.

We are developing a high-fidelity operating room (OR) experience capable of both a single and multi-player format to allow surgical residents and advanced trainees to learn how to perform the peripheral nerve surgeries described. Patient case and OR simulations will be done under the guidance of a virtual coach to provide real-time feedback. The simulations will be followed by a debriefing and constructive, personalized discussion of the simulation and the trainee's decisions.

The VPNA's data and analytics dashboards allow trainees to assess skill improvement and identify specific learning needs. The built-in learner management system facilitates easy integration into any existing curricula. The infrastructure of the VPNA supports reconfiguration and customization to address the training needs of different audiences - thus allowing the platform to be used to train healthcare professionals at any level as well as patients.

Figure 2. Trainees begin their explorations of nerve anatomy through the Male and Female Peripheral Nervous System overview modules. These modules allow for a dissection through muscle and connective tissues and the location of nerves throughout the human body. Individual nerves can be located, and their respective functions observed. Module captured with permission from BioDigital.

The VPNA is accessible by mobile device or computer using any Internet Web browser. It can be used with a VR headset and data gloves to allow for an immersive, hands-on experience, and real-time haptic feedback.

The first application of the academy

We are developing the first pilot course to assess the efficacy of the VPNA in enhancing medical student competency in the peripheral nervous system. Our pilot team consists of experts in the field, curriculum leaders and other stakeholders at the Johns Hopkins School of Medicine, and the BioDigital platform. Following the Office of Medical Student Curriculum's (OMSC) Process for Curricular Enhancement, the feasibility of curricular integration was first discussed with the OMSC and the Medical Student Senate (MSS). The VPNA team was approved to conduct a needs assessment to evaluate areas within the existing curriculum that did not address or could be enhanced by the content of the VPNA. First, the VPNA team assessed student and faculty impressions of the existing content to identify themes for improvement. Themes gathered from two groups of ten participants consisting of plastic surgeons and medical students in

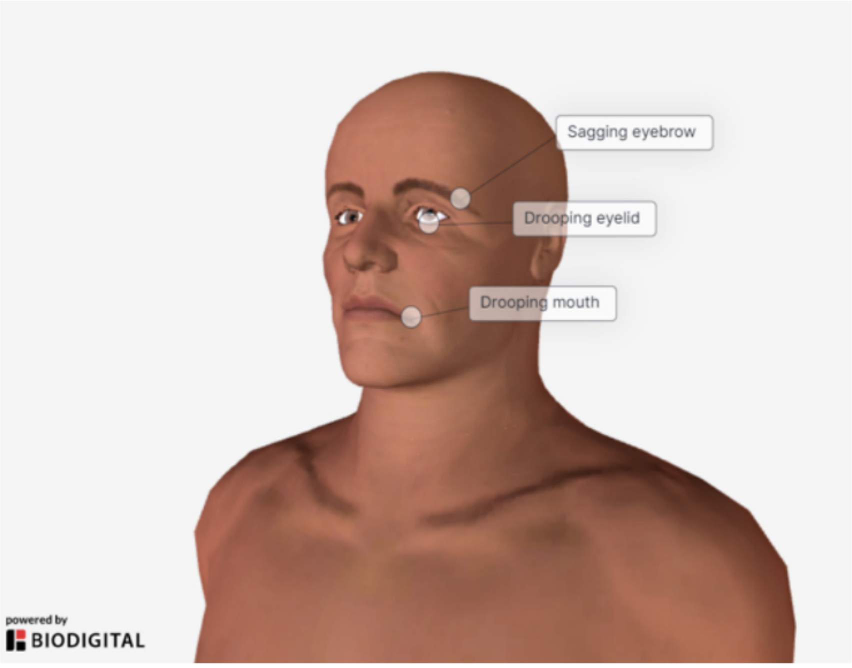

Figure 3. Individual nerve disorders, such as Bell's Palsy featured here, use game-based learning to train students on appropriate diagnostics and treatment. Trainees interact with avatars and learn to identify the signs and symptoms of over 25 peripheral nerve disorders. Module captured with permission from BioDigital.

an informal setting included general nerve physiology, individual nerve function, nerve disorders, and appropriate diagnostics/treatment. Surgeons expressed a need for early diagnosis and referral from primary care and other specialties as they frequently saw patients with delayed care. This was similarly noticed by medical students during their clinical exposure. Medical students within their preclinical years also described a large focus on the central nervous system over the peripheral nervous system within their neuroscience curriculum. From these themes, 65 individual topics (i.e., ulnar nerve, carpal tunnel syndrome) were then listed. Individual topics underwent two rounds of pretesting with five participants consisting of plastic surgeons and medical students in an informal setting.

The VPNA team then conducted a lecture-by-lecture assessment of the medical student curriculum at Hopkins to characterize if and how these individual topics were covered. The team worked closely with curriculum leaders to ensure nothing was missed. Among the courses searched were Anatomy, Pre-clinical Neuroscience, and Neurology Clerkship. Of the 40 topics assessed, 29 (72%) were present within the curriculum. However, the topics were most often briefly described (i.e., one slide within a lecture) or were only included within a graphic or table. Upon completion of the needs assessment, the VPNA was approved for implementation as both a supplement to existing topics and an avenue for new topics. Based upon our needs assessment of the Johns Hopkins School of Medicine curriculum, we have deemed the VPNA would be appropriate and beneficial to be included as a component of the Pre-clerkship Curriculum and the neurology clerkship. We have partnered with the course directors of the Pre-clerkship Curriculum to utilize the small group sessions already built within the curriculum to test the VPNA against the standard educational content. During the neuroscience core, half of the small group sessions will have unlimited access to the VPNA, while the remaining half will complete the standard course material. At the end of the core, there will be an assessment of learner satisfaction with the course material and a quiz on content specific to the peripheral nervous system. Final course exam scores will also be compared. We hypothesize that the VPNA will greatly improve overall course exam scores as well as provide a more enjoyable learning experience.

Within the Neurology core, half of the rotating students will be granted, randomly, access to the VPNA. At the end of the core, all students will take the standard National Board of Medical Examiners (NBME) Neurology core exam. Scores will be compared between the VPNA and standard education students. We hypothesize that students who can study with the VPNA will achieve higher scores on their NBME exams. Although not intended to be studied during the pilot course, it is our hope that repeated exposure to the VPNA during the pre-clerkship curriculum and neurology clerkship will lead to better retention of knowledge on the peripheral nervous system.

Upon conclusion of these pilot studies, we aim to have the support to permanently implement the VPNA at the Johns Hopkins School of Medicine and to expand to other medical schools.

CONCLUSION

The Virtual Peripheral Nerve Academy aims to provide an immersive platform for medical students to learn about the peripheral nervous system and gain competency in treating real-life nerve pathologies. This training can be easily integrated into existing medical school curricula. By increasing medical students' knowledge of how to identify and treat peripheral nerve disorders at both pre-clerkship and clerkship levels, we hope to create a lasting familiarity with the peripheral nervous system regardless of their residency choice. In doing so, we hope to reduce barriers in access to care for patients with peripheral nerve injuries by increasing the number of healthcare professionals versed in their care. The Virtual Peripheral Nerve Academy began pilot evaluation in March 2022, and data collection will continue through December 2022. Following pilot completion and iterative refinement, it will be released with all components to the public in July 2023.

DECLARATIONS

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Authors' contributions

Made substantial contributions to conception and design of the Virtual Peripheral Nerve Academy: Lee EB, Podsednik A, Khoo K, Cheema A, Cabrejo R, Shen C, Rosen J, Dellon AL

Designed and established pilot program: Lee EB, Dellon AL

Availability of data and materials

Not applicable.

Financial support and sponsorship

None.

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication
Not applicable.

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