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Application of NIR-II fluorescence real-time image guidance in surgery for CVI patient

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Abstract

Chronic Venous Insufficiency (CVI) often presents with the tortuosity and dilation of small veins, posing challenges for naked-eye identification. Complete removal of all affected vessels in a single operation remains difficult, with a high risk of postoperative recurrence. In this paper, we report a case of NIR-II-assisted CVI surgery, which represents the first attempt to visualize CVI vascular lesions. Through the administration of Indocyanine Green (ICG) imaging agent into the dorsal foot veins, precise visualization of vascular crosslinking and trajectorie was achieved, facilitating the guidance of venous laser ablation and foam sclerotherapy procedure. Moreover, this study marks the inaugural application of near-infrared imaging to CVI disease both domestically and internationally. Compared to the conventional NIR-I (Near-Infrared-I) window, the NIR-II (Near-Infrared-II) window enables exploration of deeper tissues at the centimeter level and achieves higher resolution at the millimeter level. Finally, NIR-II ICG vascular imaging delineates clear vascular position and trajectorie, assisting surgeons in effectively closing diseased vessels, thereby reducing the risk of recurrence.

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Keywords: Chronic venous insufficiency; NIR-II; Indocyanine green; Optical imaging; Real-time image.

Introduction

Chronic venous insufficiency is a prevalent vascular disorder distinguished by the tortuosity and dilation of superficial veins, often accompanied by symptoms such as limb heaviness, pain, and skin discoloration. Surgical treatment is primarily indicated for patients with more severe conditions [1,2]. Precise localization of diseased vessels during surgery is paramount for preserving functional veins while removing pathological vessels to mitigate postoperative recurrence [3]. However, achieving this optimal visualization and surgical outcome remains challenging in individuals with CVI. Due to the tortuosity of venous vessels, identifying and tracing distal or small vein lesions through visual inspection and palpation proves arduous [4]. Current clinical methodologies, such as ultrasound and segmental pressure testing, evaluate lower limb venous function but possess limited capabilities in visualizing diseased vessels [5]. There exists an urgent need for innovative techniques enabling real-time vascular imaging during surgery. Recently, NIR-II fluorescence imaging (1000-1700 nm) has demonstrated significant advantages in vascular assessment [6]. Using FDA-approved ICG as a contrast agent, NIR-II imaging offers outstanding contrast, sensitivity, and resolution, surpassing the performance of the NIR-I (700-900 nm) window [7]. It enhances detection depth, providing surgeons with “enhanced vision” to assist in intraoperative lesion removal while preserving functional vessels [8]. This study demonstrates the visualization of tortuous vessels in patients with lower limb varicose veins during surgery using NIR-II fluorescence imaging.

Case presentation

A 56-year-old woman with CVI in her left lower limb presents with tortuous vessel courses and localized healing ulcers. The preoperative treatment plan includes endovenous laser therapy of the great saphenous vein combined with foam sclerotherapy. However, visualization of the diseased vessels remains challenging based on existing clinical experience, thus increasing the complexity of the surgical procedure and posing a significant risk of recurrence. Consequently, we conducted NIR-II optical imaging to enhance visualization of the lesions. Real-time imaging of the affected vessels was performed using the NIR-II imaging system. All procedures in this study were approved by the Second Hospital of Shanxi Medical University ([2024]YX214), and written informed consent was obtained from the patient.

The patient was placed in a supine position with a tourniquet secured around the knee. ICG was injected into the left dorsal foot vein (Dandong Yichuang Pharmaceutical Co., Ltd., China). Subsequently, compression of the gastrocnemius muscle and passive ankle pumping were performed. NIR-II fluorescence imaging revealed varying degrees of signal enhancement at different lesion sites. Initially, enhanced fluorescence signals were observed around the healing venous ulcer on the medial aspect of the ankle (Figure 1). Localized pigmentation lesions were noted on the inner aspect of the left calf. Post-contrast imaging identified areas of varicose veins, with visible vascular reticular structures in grayscale (Figure 2). Tortuous vessel connections and trajectories were visible on the outer aspect of the left calf, with clear vascular delineation under NIR-II imaging (Figure 3). Leveraging this lesion visualization guided by real-time fluorescence imaging, surgeons effectively closed the diseased vessels while preserving functional ones, leading to a successful surgical outcome. No allergic reactions were reported post-ICG injection, and there were no significant symptoms of nausea or vomiting postoperatively. The patient experienced uneventful postoperative recovery, maintaining compression therapy with elastic stockings on both lower limbs during follow-up.

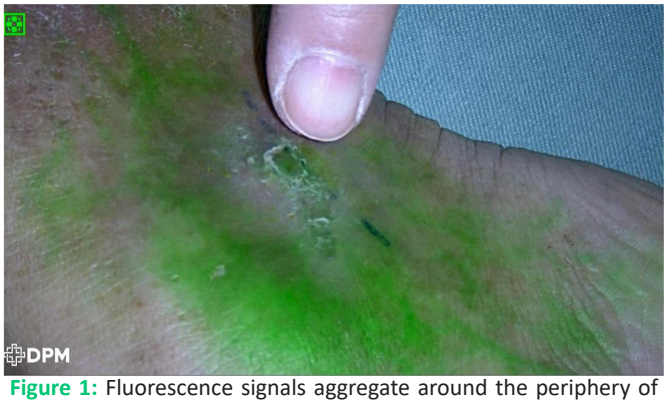

Figure 1: Fluorescence signals aggregate around the periphery of the venous healing ulcer.

Discussion/conclusion

Precision treatment plays a vital role in the postoperative recovery and recurrence reduction among patients with lower limb varicose veins. However, the limitations in visualization methods have increased the surgical complexity. Although ultrasound-guided varicose vein surgery has demonstrated clinical benefits, intraoperative manipulation inconvenience and imaging constraints have hindered its efficacy [9]. Currently, real-time intravascular NIR-I fluorescence imaging, recognized as a potent technique, has found extensive application. It has been employed for precise identification of lung nodules and abdominal cancers in thoracic and general surgery [10]. Recently, reports have emerged on the inaugural intraoperative navigation of human liver tumors using NIR-II [11]. NIR-II fluorescence imaging has garnered significant interest due to its diminished tissue light scattering and increased penetration depth compared to NIR-I fluorescence imaging. Meanwhile, ICG, an FDA-approved contrast agent for over 60 years, has been validated for NIR-II imaging [12].

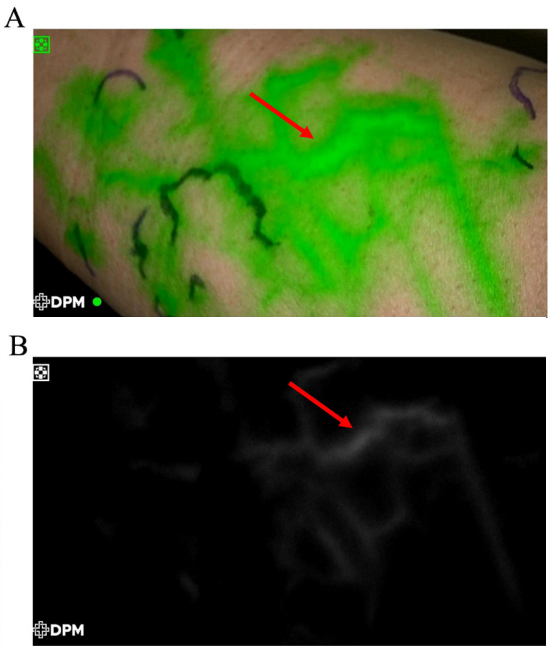

Figure 2: (A): Varicose veins are visualized (with pseudo-color). **(B):** Vascular cross-linked structures were visible in grayscale. The red arrow indicates the same area as the varicose vessel.

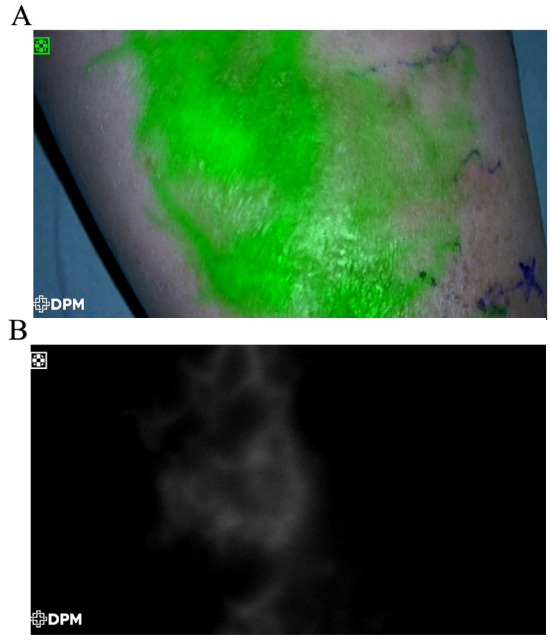

Figure 3: (A): Localized pigmentation is visible (with pseudo-color) **(B)**: Vascular reticular structures were visible in grayscale.

In our study, NIR-II imaging was utilized, with ICG injected into the dorsal foot vein. Fluorescence signals emerged in the lower limb veins, enabling clear visualization of vascular boundaries. This facilitated surgeons in evaluating vascular connections and trajectories. Guided by real-time fluorescence imaging, surgeons effectively closed diseased vessels while pre-

serving functional ones, thereby diminishing the recurrence risk. This pioneering attempt at visualizing CVI vascular lesions lays a pivotal groundwork for ongoing surgical optimization and prognosis enhancement, stimulating novel ideas and approaches for subsequent CVI surgeries. Our report recorded no adverse events, and venous injection of ICG exhibited long-term stability. In the future, we intend to broaden the inclusion of varicose vein patients and delve deeper into the potential of combining ICG with NIR-II imaging for intraoperative navigation.

Declarations

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Conflicts of interest: The authors declare no conflicts of interest.

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