



COST-EFFECTIVENESS AND PERFORMANCE OF A PROTOTYPE VEIN DETECTOR FOR LOW RESOURCE SETTINGS: AN APPROACH USING THE NEAR INFRARED SPECTRUM

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Abstract

Objectives: To assess the vein detectability of a prototype (do-it-yourself) vein detector as an efficient and affordable portable device, which can greatly aid in cannulation and improved patient care in low resource settings.

Methodology: A comparative study was carried out at the Pediatric and Medicine wards of HIT Hospital, Taxila Cantt. All eligible patients admitted were consecutively recruited, resulting in a total sample size of 81 participants. Each subject was sequentially assessed for median cubital vein visibility using both the DIY vein detector and a commercial neonatal intensive care unit-grade standard detector. The visibility of veins was recorded as either visible or not visible by two independent observers, and the findings were correlated with variables such as age, gender, skin tone, and body mass index. Data were analyzed using SPSS-26. Inter-observer reliability was evaluated using Cohen's Kappa coefficient to determine agreement between observers.

Results: The median cubital vein detection with the DIY vein detector had an average vein visualization rate of 90.75%, whereas the gold standard had an average of 88.9%. Interrater reliability was tested, a Kappa score of 0.78 established a substantial agreement between the two observers. General vein visibility was outlying as the interrater Kappa statistic was 0.000 meaning that there is no meaningful consensus. A considerable correlation between Median Cubital vein visibility and BMI was found ($p < 0.004$) in our DIY vein detector which was non-attributable to the gold standard vein detector.

Conclusion: The DIY alternative has demonstrated promising outcomes, particularly noting limitations in subjects with higher body mass index. While the observed results could potentially be attributed to chance, they are compelling and offer a glimmer of optimism for the development of vein detectors like ours as cost-effective alternatives that could match or even surpass the efficiency of pricier models.

Keywords: Anti-Oxidant Activity, DPPH free radical scavenging activity, *Ruellia tuberosa*, Total phenolic

Introduction

The intravenous (IV) route of administration is widely used in hospitals, with approximately 90-95% of patients receiving their treatment through this method.¹ Moreover, the significance of this route is further highlighted by the staggering number of over one billion venipunctures performed each year for medical laboratory testing.² These procedures, involving the insertion of a cannula into a vein, play a crucial role in facilitating a wide range of medical interventions.³ In order to perform the cannulation procedure, the first step is to make the target vein visible. This is typically done by using a tourniquet or gently tapping the site.⁴ However, not all veins are easily visible, making cannulation challenging for many medical practitioners. Factors such as paediatric patients, dehydration, dark skin color, obesity, poor vein quality, aging, and the lack of skill of the individuals performing the procedure can further complicate the process.⁵

The interaction of infrared radiation with human blood has two implications that allow us to derive a practical inference, which in this particular instance is our vein detector. Infrared radiation is capable of penetrating human skin up to 3 mm deep.⁶ Within the skin, it is exponentially absorbed by reduced haemoglobin, which is essentially deoxygenated, in comparison to the surrounding tissue and appears dark.⁷

The importance of successful cannulation cannot be overstated, as failure or prolonged attempts can have adverse effects on patients. Apart from causing distress and trauma, unsuccessful cannulation can lead to subcutaneous hemorrhage from repeated attempts, increased pain, and even extreme reactions, particularly in children, adults, or patients with mental illness.^{4,8} While advanced vein finder devices exist and have shown promising results in visualising vein course accurately, their widespread adoption is hindered by the high cost associated with commercially available equipment.⁹

The purpose of present study is to present an alternative, cost-effective method for visualising veins. We developed a prototype vein detection device that can be implemented for less than \$2 USD. By providing a low-cost solution, we hope to increase access to vein visualisation technology, particularly in low-resource settings where expertise may be limited, as is often the case in developing countries. This way, we can enhance the success and efficiency of cannulation procedures, ultimately improving patient outcomes and comfort during medical interventions.

Methodology

A comparative study was carried out at the Pediatric and Medicine wards of HIT Hospital, Taxila Cantt collected in March 2022, after ethics approval from the Institutional review board of HITEC IMS, to evaluate the effectiveness of a low-cost, self-assembled vein detector against an industry-grade standard vein detector in visualizing the median cubital vein. The sample size of 81 consisted of patients admitted

to the Pediatric and Medicine ward at HIT hospital in Taxila Cantt. Purposive sampling was employed to select participants, ensuring that all relevant data collected over a span of one week was included. The inclusion criteria for the study involved all patients admitted in the Pediatrics and Medicine ward. Only non-consenting patients were excluded. The inclusion criteria ensured diversity among participants in terms of age, gender, skin tones, as well as varying body mass indices (BMI). In order to collect the required data, a systematic approach was followed. All subjects were sequentially subjected to vein detection using two different methods: our DIY vein detector (Fig. 1) and an industry-grade standard vein detector commonly used in NICUs. This comprehensive approach allowed us to consider potential variations in vein visibility based on demographic factors.

The prototype consisted of an outer enclosure housing a compact electronic circuit powered by a 9 V DC supply. The internal circuitry was embedded beneath the frame (Fig. 2). The system is powered by a 9-V DC battery connected in series with a 2 k Ω resistor and a switch, supplying current to an array of high-intensity red light-emitting diodes (LEDs) arranged in parallel. This configuration ensures uniform illumination and stable current distribution across all emitters for optimal subdermal vein visualization. The study employed a blinded observational design. Two independent observers (Observer 1 and Observer 2) participated in the study. A third person assisted by holding the vein finder device over the vein location (Fig. 3). The observers then located the vein on their own and documented their results on separate forms, without consulting each other or the assistant. Initially, this process was conducted in a well-lit room. After both observers had recorded their findings, the lights were turned off, and the room was darkened. The observers then repeated the vein location process, one at a time, in the dark room, using only the vein finder device for guidance. This allowed for a comparison of vein detection accuracy between the well-lit and dark room conditions. Throughout the study, the observers did not discuss or compare their findings with each other or the assistant, ensuring an unbiased assessment of vein detection accuracy.

This study accounted for several key variables that could impact vein detection accuracy, including: Participant demographics (age, gender, weight, height, and body mass index), skin tone and lighting conditions: two distinct settings were tested, namely a well-lit room and a dark room. The observers' findings were recorded for each participant under these varying conditions, allowing for a comprehensive analysis of the vein detection accuracy. Performance was defined as the visibility of median cubital vein and general vein visibility that is any vein visible to an observer in one participant. Cost effectiveness was defined as the cost of making the device available for use on patients, including cost of development. The collected data was then analyzed using IBM SPSS 26 software. Means and standard deviations were calculated to summarize the data, providing a comprehensive overview of the study findings, a kappa score was established to determine the reliability of the results obtained.

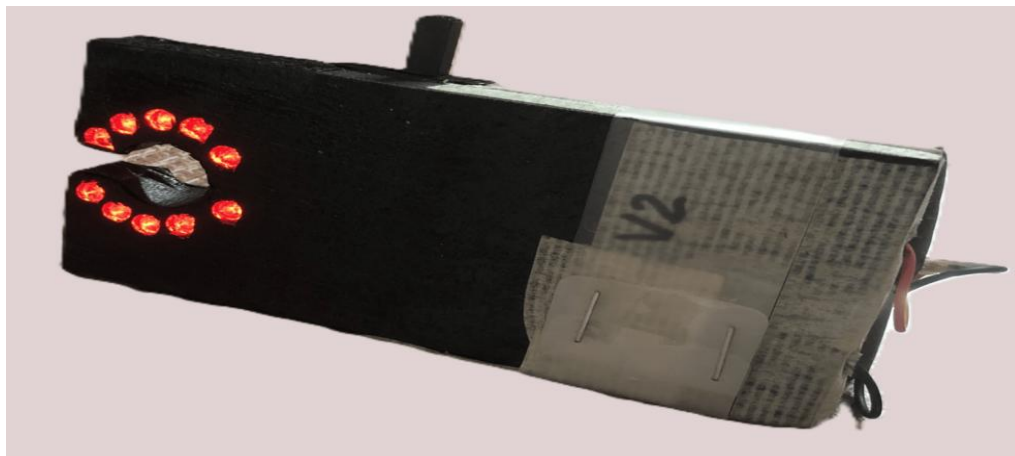


Fig. 1: The DIY vein finder in its powered-on state

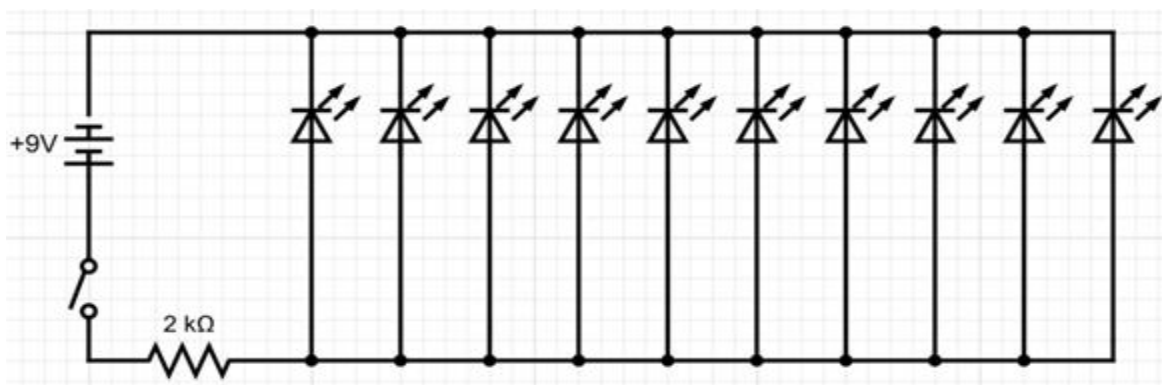


Fig. 2: Circuit diagram of the DIY vein detector prototype

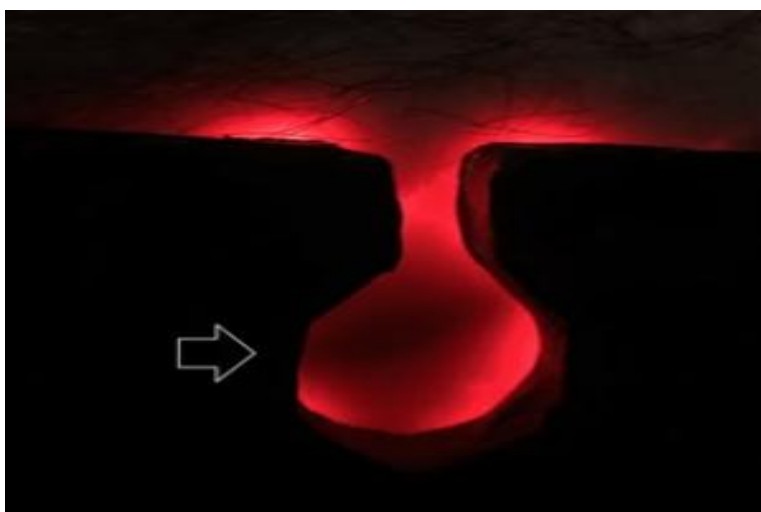


Fig. 3: The image illustrates the device in use; the dark streak in the red illumination is an identified vein

Results

The mean age was 26.95 ± 21.53 years and a mean body mass index was 20.84 ± 5.86 kg/m². The median age and body mass index are 23.00 and 21.20, respectively. There were 51 (62.96%) males and 30 (39.14%) females (Table 1). The efficacy of vein detection using both the DIY vein detector and the gold standard technology was assessed in this comparative study. The results revealed that the DIY vein detector achieved an average vein visualization rate of 90.75% for detecting the Median Cubital vein, while the gold standard device had an average rate of 88.9%. This indicates that both methods were effective in visualizing the targeted vein, with the DIY vein detector slightly outperforming the gold standard. To assess the reliability of the findings, interrater reliability was tested using a Kappa score. The analysis showed a substantial agreement between the two observers, with a Kappa score of 0.78. This indicates a reliable and consistent assessment of vein visibility between the two methods (Table 2). However, when considering the general vein visibility as a whole, the interrater Kappa statistic was 0.000, indicating a lack of meaningful consensus between the observers. This suggests that while there was agreement on the specific Median Cubital vein, there were variations in vein visibility for other veins assessed. Furthermore, an interesting finding emerged from the analysis, indicating a significant correlation between Median Cubital vein visibility and BMI ($p < 0.004$) when using the DIY vein detector. This correlation was not observed when using the gold standard vein detector. This suggests that BMI may influence the visibility of the Median Cubital vein when using the DIY vein detector, but not with the gold standard device (Table 3).

The effectiveness of both the DIY vein detector and the gold standard device in visualizing the Median Cubital vein noticed. The DIY vein detector showed a slightly higher vein visualization rate. However, there were variations in general vein visibility and a correlation between Median Cubital vein visibility and BMI was observed with the DIY vein detector. These results show how the DIY vein detector can be useful in clinical settings and offer insightful information about the variables that might affect vein appearance.

Table 1: Demographic profile of the subjects

Variable	Mean $\pm$ SD
Age (years)	26.95 $\pm$ 21.53
Body mass index	20.84 $\pm$ 5.86
Gender	
Male	51 (62.96%)
Female	31 (39.14%)

Table 2: Detection rates median cubital vein with both modalities

Detection rate MCV (DIY vein finder)	Detection rate MCV (Industrial grade vein finder)
90.75%	88.9%

Table 3: Comparison of cost-effectiveness of prototype of both modalities

Cost of prototype DIY vein finder	Cost of industrial grade vein finder
< \$2	Ranges from \$500-\$2000

Discussion

In the present study the average vein visualization rate of DIY vein finder is 90.75% for detecting the median cubital vein, while the gold standard device had an average rate of 88.9%. Miller et al¹⁰ found that accu-vein had an average vein visualization rate of 89.8% for median cubital vein detection, which is closely comparable to the average rate observed in our study using a DIY vein detector, at 90.75%. This study also noted the importance of interrater reliability testing, which we also performed and found a substantial agreement between observers.

In our DIY Vein Finder, we used infrared light which showed excellent vein detection capability. A study led by Chandra et al¹¹, designed a vein finder using RGB LED with wavelengths ranging from 600 to 696nm. The device successfully detected veins in 10 patients with varying ages and skin tones. This suggests the significant use of Infrared light in the detection of veins. Similarly, Alwazzan¹² stated that a low-cost system designed to detect veins in the palms of hands using Infrared LEDs produces effective and accurate imaging of veins in palms. Likewise, we utilized Infrared LEDs in our DIY vein detector to identify the median cubital vein. Comparing it with a gold standard vein detector, we obtained excellent results, while maintaining cost-effectiveness.

Also, a study done by Barreras et al¹³ showed that the use of Near Infrared Light decreases the number of attempts and enhances overall success rates in obtaining peripheral venous access in children with special healthcare needs. Our study also highlighted that our DIY vein finder can be effectively used for selecting veins for venous access in both children and elderly. Fukuroku et al¹⁴ suggesting that a vein visualization system using near-infrared light (vein display) is effective for safely and accurately selecting venipuncture sites, particularly in elderly patients. Our study also proved the effectiveness of our DIY vein finder in visualization and selection of veins for diagnostic or therapeutic purposes.

Another study focusing on peripheral venous access in children using infrared visualization devices conducted by Vyas et al¹⁵, concludes that these devices are relatively expensive and might not be easily available in smaller hospitals and clinics. Our study used an inexpensive DIY vein finder costing less than \$2 which proved significant in detecting veins in patients of all ages, from children to elderly.

Limitations

While our study provides promising results for the efficacy of the DIY infrared vein finder, there are some limitations to consider. The criteria used to classify general vein visibility were ambiguous or poorly defined, or that the observers required additional training or standardization in their evaluations. Some studies have used a grading scale to evaluate the visibility and accessibility of veins, taking into account factors such as the size, depth, and location of the veins, by doing so we can increase the reliability and validity. Additionally, the study population consisted of only 81 subjects, which may limit the generalizability of the findings.

To further confirm the DIY vein detector, larger clinical trials involving a variety of groups should be part of future study. In addition to research evaluating long-term durability and usability in comparison to commercial devices, technological advancements are required to increase performance in people with higher BMI. While cost-effectiveness evaluations can direct its adoption into clinical settings, obtaining input from healthcare experts can help assess user integration accessibility and simplicity of use.

Together, these initiatives will increase knowledge of the device's potential and aid in its transformation into a useful, reasonably priced substitute for standard medical care.

Conclusion

With a marginally similar visualization rate (90.75% vs. 88.9%), the do-it-yourself (DIY) vein detector performs similarly to the industry-grade standard device in visualizing the median cubital vein. The prototype's reliability is further validated by the significant inter-observer agreement ($\kappa = 0.78$). Furthermore, the DIY detector's sensitivity to patient-specific characteristics is highlighted by the substantial association between vein visibility and BMI that was only found with it. Even if some may be attributed to chance; this prototype offers a useful and effective substitute for peripheral vein localization in low-resource clinical settings due to its affordability, portability, and simplicity of assembly, potentially improving patient care in resource limited settings.

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