Feasibility Study of Identifying Blood Vessels with A Radio-Frequency Resonator

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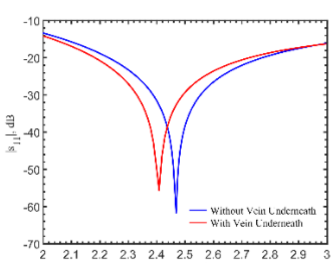
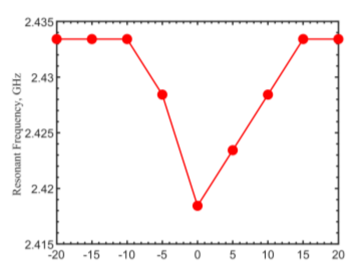
Venipuncture is a procedure for phlebotomy to draw blood from a vein for laboratory tests. Critical errors in phlebotomy, including improper vein selection and insertion, produce serious risks and liability in healthcare practice (DJ. Ernst, *J. Healthc Risk Manag*, 1998). Although venipuncture has been a routine procedure in large populations, with estimated 1.4 billion cases a year in the US (Center for Health Statistics, *NHAMCS*, 2016), errors frequently occur due to unpredictable, random, and widely variable skin and tissue conditions in people. Common complication cases include hematoma formation and pain due to nerve injury, as well as fear and phobia. Severe complications include cases of arterial puncture, thrombus, and syncope (HJ. Galena, *J. Fam. Pract*, 1992) (OY. Buowari, *Adv. Biosci. Biotechnol*, 2013). These cases occur mainly due to improper site selection and consequential needle insertion. They can be avoided with additional noninvasive sensing modality, besides human judgment with the caregiver's visual inspection or touch to palpate the vein with fingers. Ultrasound and near-infrared (NIR) have been applied to identify vein locations. Ultrasound images are noisy, blurry, and sensitive to placement, while NIR is limited to about 3 mm depth in tissues. These factors prevent them from practical uses as studies have shown no significant benefit by using them compared to manual procedures (JM. Leipheimer, *Technology (Singap World Sci)*, 2019) (SJ. Curtis, *Can. Med. Assoc. J*, 2015).

This work is to explore the feasibility of utilizing low-power microwave signals to identify vein locations noninvasively. The dielectric properties of blood vessels are significantly different from those of skin and muscles because of the high water content in the blood plasma. Previously, we have demonstrated a planar resonator based on a compact impedance-matched loop (S. Bing, *J. of Microwaves*, 2023) that can detect water concentrations inside biological materials. A copper loop was fabricated by photolithography and wet-etching on a flexible polyimide substrate. A pad in the loop center tuned the impedance with distributed reactances to achieve a high quality-factor. The resonant frequency shifts and reflection coefficient magnitude changes distinguished different tissues under the resonator that was confirmed on the skin.

Simulations were performed to validate the feasibility of recognizing the median cubital vein on the forearm. Measurements in phantoms have been conducted to confirm the validity of simulation models. Complex permittivities were measured by a dielectric probe on the skin across the median cubital vein, and the values were used in 3-D finite-element models of veins in tissues. Figure 1(a) shows the resonance changes for the vein with a 4.9-mm diameter at a depth of 3 mm in tissues. The vein wall thickness is 0.35 mm. The frequency shift indicates the existence of the vein. For a 2.3-mm diameter vein at a depth of 6 mm, a raster scan of 5-mm steps across the skin surface shows a clear indication of the vein location by the resonant frequencies in Fig. 1(b). The magnitude changes in reflection coefficients were used along with the resonant frequency shifts to enhance the contrasts in raster scans on the skin for better identification.



(a)



(b)

Figure 1. (a) Reflection coefficients between the cases with and without blood vessels under the resonator. (b) Resonant frequencies by a raster scan across the blood vessel, located at the zero, under the skin.

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