Abstract

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The non-invasive evaluation of cardiovascular hemodynamics is based on the characterisation of the intricate interplay between cardiac function and respiratory dynamics. The present dissertation addresses critical challenges in this domain by integrating two complementary approaches: automated ultrasound imaging of the inferior vena cava (IVC) and advanced signal processing of cardiorespiratory synchronisation.

Current IVC assessment using M mode and B mode ultrasound is constrained by the complex three dimensional geometry of the vessel and dynamic respiratory motion, while manual frame selection limits reproducibility. To resolve these impediments, we developed a real time semiautomated edge tracking algorithm that enables continuous IVC monitoring. By decomposing the acquired data, we successfully isolated the cardiac and respiratory components that are the primary determinants of IVC dimensional variations. In the clinical domain, we use this software to implement non-invasive right atrial pressure (RAP) estimation. We achieved a classification accuracy of 71% using machine learning models in a cohort of 170 patients, outperforming existing guideline based methods (61%). Further application to hyponatremia management enabled 81% accuracy in differentiating euvolemic from hypervolemic states. Additionally, validation in 33 healthy subjects confirmed the sensitivity of IVC diameter to acute volume changes, observing notable diameter decreases post exercise and prompt normalisation following rehydration.

From a technical perspective, we proposed a novel multiplanar imaging method combining simultaneous long axis and short axis views, revealing that multidimensional approaches can reduce measurement errors significantly compared to standard techniques.

Recognising that these morphological variations are driven intrinsically by the synchronisation of physiological oscillators, we extended the investigation to the ECG and respiratory signals. We developed a computational framework to quantify the phase locking between cardiac and respiratory signals during awake and sleep states, further analysing the modulation of this coupling by acoustic stimuli. This dual investigation, linking the mechanical displacement of the IVC with its driving physiological signals, paves the way for a more comprehensive understanding of cardiovascular physiology. Collectively, these contributions advance the precision of noninvasive volume status assessment with broad implications across medical and athletic domains.