Trends and Variability Analysis from Continuous Physiologic Monitoring: Phenotype of Acute Illness

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INTRODUCTION

Physiological variability and trend measurements are increasingly used by researchers to describe pathological states, provide prognostic information, and measure individualized response to therapies.[1,2] Advances in telemedicine technology and real-time monitoring allow multimodal, multi-technique bio-signal acquisition and a minefield of data, thereby, enabling knowledge of the variable phenotype of acute illness. The study of disease dynamics, or how disease states change with respect to time, is proving key to understanding abnormalities in underlying physiologic control mechanisms. [3] Collection of dynamic time series data in acute illness is the key first step in obtaining a system dynamics oriented perspective of critical illness and injury. [4] In order to study these events closely, we used NexfinHD, an FDA approved hemodynamic monitoring device to assess hemodynamic profiles in patients presenting to the Emergency Department (ED) with acute stroke. Since optimizing cerebral perfusion is paramount in managing ED patients with acute stroke, we assessed the global hemodynamics and trends in these patients by linear and non-linear dynamics.

It is postulated that there is significant variability in hemodynamics of patients presenting to the ED with acute stroke, not estimable by clinicians, which can be captured by continuous data acquisition and these trends can be detected by mathematical time-series techniques which can benefit future prediction modeling and individualized therapies.

METHODS

NexfinHD, an FDA approved noninvasive continuous cardiovascular monitor with finger-cuff technology, was used to measure beat-to-beat blood pressure (systolic (SBP), diastolic (DBP), and mean (MAP)), heart rate (HR) alongwith cardiac index (CI), stroke volume (SV), systemic vascular resistance index (SVRI), dp/dt (left ventricular contractility) in a cohort of ED patients presenting with acute stroke. These were compared to oscillometric measurements in a convenience sample of patients. NexfinHD measured cardiac index (CI) and systemic vascular resistance index (SVRI) were compared to physician estimates in this pilot study. Return mapping allowed for visualization of outlying data points (primarily due to artifact), which, were then filtered out. Time series for hemodynamic profile were visually classified into 5 patterns: no change, outliers, temporary level change, permanent change and trend. The same series were analysed offline with low-order auto-regressive (AR) models and Phase Space (PS) models.

RESULTS

A total of 59,435 beat-to-beat hemodynamic data points were recorded over a two hour period for 12 acute ED stroke patients using NexfinHD. From 80 paired BP and HR readings, there was no difference found between the NexfinHD and oscillometric measures for SBP ($p=0.14$), DBP ($p=0.1$) or HR ($p=0.4$). There were significant differences between clinician and NexfinHD measures of HP ($p<0.001$). The diagnostic accuracy of clinicians was 36% for CI and 54% for SVRI. Trend analysis showed median (range) MAP of 106 (45-160) mm Hg; CI of 2.8 (1.7-5.8) $l/min/m^2$; SVRI of 3138 (2410-4209) $dyne\text{-}sec/cm^5/m^2$ and dp/dt 1282 (856-1901) mm Hg s^{-1}. Similar variability was seen with non-linear analysis. 96 time-series of hemodynamic parameters were assessed and visually classified trends were detected by the AR and PS models. In this exploratory study of acute ED stroke patients, NexfinHD blood pressure measurements were not different from usual oscillometric measurements. NexfinHD showed patients with elevations in SVRI and dp/dt, and wide variability in CI. ED physician estimates of hemodynamics were poor. Statistical patterns in univariate emergency department physiologic time series can reliably be detected with AR models and PS models.

It is important that the increased ability of physiological data acquisition is matched by its potential of knowledge translation otherwise the data becomes useless and the databases become data "dumps. Continuous monitoring with trend analysis has the potential to individualize therapeutic interventions, optimize hemodynamics, and improve cerebral perfusion in stroke patients in the ED. Future scope remains for the tight integration of visualization techniques with traditional techniques from such disciplines as statistics, machine learning, operations research, and simulation leading to combination of automatic data mining algorithms with the intuitive power of the human mind, improving the understanding of variability of disease phenotype in diagnosis and treatment in stroke patients.

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Manuscript submitted on Feb 12, 2010 for the 1st AMA-EMBS Meeting on Personalized Medicine. This work would like to acknowledge modest financial support from BMEYE (Amsterdam, Netherlands), the makers of the NexfinHD device

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