Intraoperative Arterial Pressure Waveforms Shows Temporal Structure Complexity Correlated with Acuity of Liver Transplant by Pulse Wave Manifold Learning Analysis

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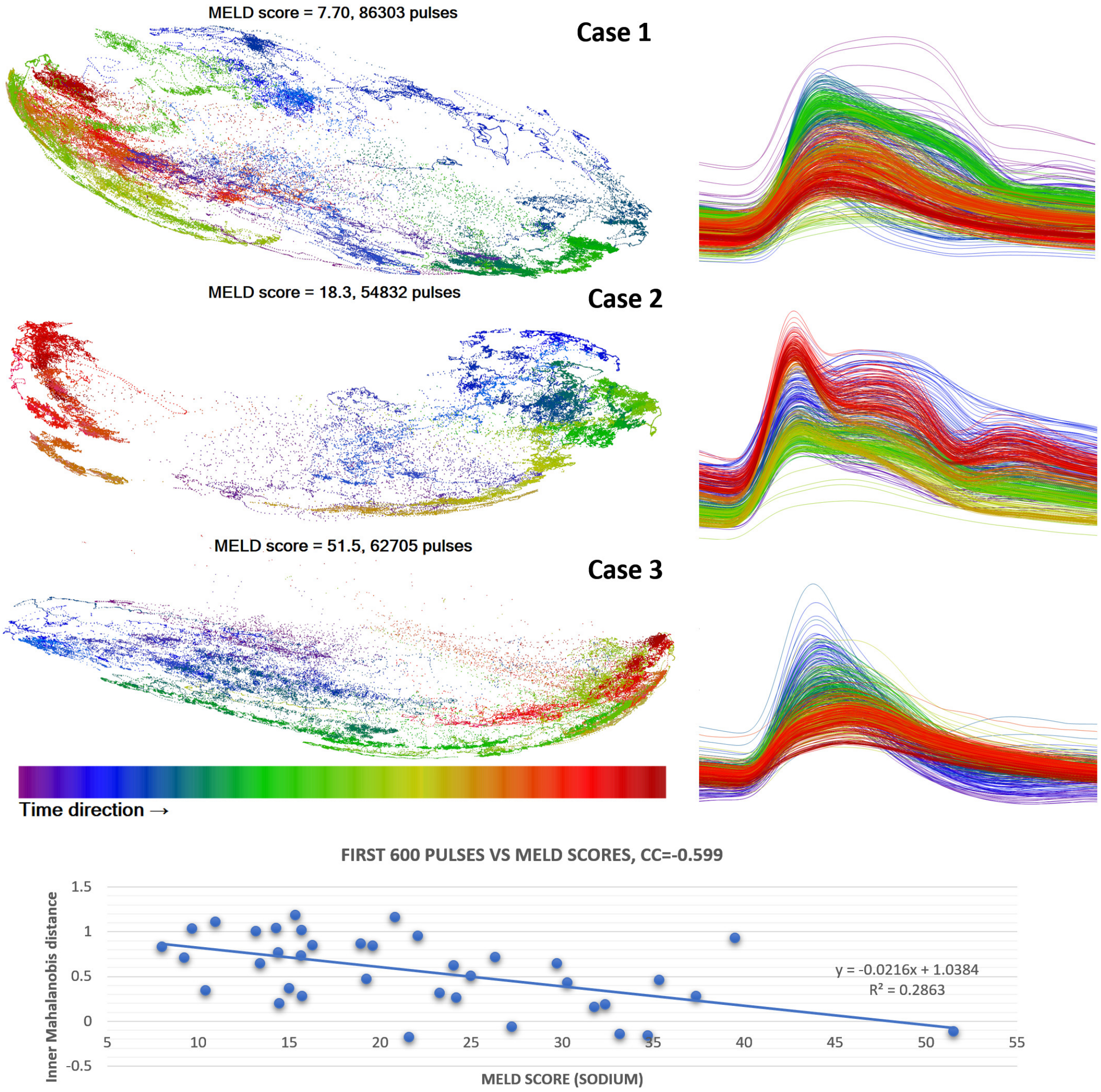
Introduction: Arterial blood pressure (ABP) waveform reflects numerous aspects of the human circulation system. The waveform morphology has been exploited in clinical scenarios to predict hypotension, to assess arterial stiffness, or to derive the profiles of the cardiovascular system. As the intrinsic physiological mechanisms are continuously regulating to maintain homeosis, the temporal evolution information may reveal this dynamic process, which is not addressed by the above ABP waveform applications.
Recipients of the liver transplantation range from relatively stable chronic liver disease to critically fulminant hepatic failure. Careful preoperative evaluation and preparation is paramount to this life-saving surgery. To assess the outcome preoperatively, the Model for End-Stage Liver Disease (MELD) score was developed from lab tests including creatinine, bilirubin, INR, and sodium data. As the disease acuity may also compromise numerous physiological mechanisms for homeosis, we propose that the ABP waveforms evolving with time reflect the severity of the patient's condition.
We hypothesize that favorable condition of liver transplant recipient possesses more intricacy in the pulse waveform time evolution structure. We evaluate ABP pulse waveforms immediately after anesthetic induction as this period representing the initial status.

Methods: We conducted a prospective observational study for liver transplant after institutional ethic review board approval and the informed consent obtained from every case. We collected intraoperative physiological signal data of 39 liver transplant recipients from the standard patient monitor (GE CARESCAPE B850, GE Healthcare, Chicago, IL). To effectively measure the "inner structure" of ABP waveform, we use an unsupervised manifold learning method, diffusion map (DMap), to "condense" the temporal information into a "relatively" low dimensional structure. DMap treats every oscillatory cycle as a high dimensional data point and finds a geometric structure in high dimensional space representing the trajectory of the waveforms evolving with time. Using only the successive pulse-to-pulse waveform morphology, this unsupervised method was performed objectively without the input of medical history, lab test data, or the surgical procedure.
Quantitative measurement of the intricacy of the manifold structure was performed by the Mahalanobis distance, which is the multi-dimensional version of the famous standard deviations. The more intricacy of the structure leads to the larger inner Mahalanobis distances measured. We use information of top 10 dimensions to calculate the Mahalanobis distance, which was measured from the first 600 ABP pulses of each case to assess their "initial condition" just after the anesthetic induction. Spearman rank correlation between the distance and MLED score is evaluated.

Results: Visually presented by DMap, the ABP pulse waveform evolving with time exhibits a trajectory. The trajectory structure from the case of favorable condition (suggested by MELD score) exhibits a more intricate structure and vice versa (Fig. 1). The Spearman rank correlation to MELD score is –0.60 as high MELD score represents unfavorable outcome.

Conclusions: Intraoperative ABP pulse waveform contains the acuity information of liver transplant.

Figure 1:



Three liver transplant cases of different MELD scores (upper panel) and the Spearman rank correlation of 39 liver transplant recipients (lower panel). Their whole intra-operative ABP pulse waveforms (right column) and the different intricacy of the time evolution trajectory extracted by manifold learning (left column).