Algorithm

Algorithm to Identify Components of Arterial Blood Pressure Signals During Use of an Intra-Aortic Balloon Pump

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ABSTRACT.

Existing bedside cardiovascular monitors often inaccurately measure arterial blood pressure during intra-aortic balloon pump (IABP) assist. We have developed an algorithm that correctly identifies features of arterial pressure waveforms in the presence of IABP. The algorithm is adaptive, functions in real-time, and uses information from the electrocardiographic (ECG) and arterial blood pressure signals to extract features and numeric values from the arterial blood pressure waveform. In its current form, it requires reliable ECG beat detection and was not intended to operate under conditions of extremely poor balloon timing. The algorithm was evaluated by an expert (P.F.C.) on a limited data set, which consisted of 12 1-minute epochs of data recorded from 6 intensive care unit patients. A criterion for selection of patients was that the ECG beat detector could detect ECG beats correctly from the waveforms. The overall sensitivity and positive predictivity for beat detection were 94.04% and 100%, respectively. For feature identification, the overall sensitivity was greater than 89%, positive predictivity was 100%, and the false-positive rate was 0%. The performance measures may be biased by the criteria for patient selection. This approach to identifying waveform features during IABP improves the accuracy of measurements. The utility of using 2 sources of information to improve measurement accuracy has been demonstrated and should be applicable to other physiologic signal-processing applications.


RÉSUMÉ. Les moniteurs cardiovasculaires actuels ne permettent souvent qu’une mesure imprecise de la pression artérielle lors de l’assistance circulatorie réalisée par une contre-pulsion par ballonnet intra-aortique (CPBIA). Nous avons développé une algorithme qui identifie correctement les caractéristiques du signal de pression artérielle en présence d’une CPBIA. L’algo-

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características y valores numéricos desde la onda de presión arterial. En su forma actual, requiere buena detección de la onda R del ECG y no está diseñado para funcionar si la sincronización del BCIA es inadecuada. El algoritmo fue evaluado por un experto (P.F.C.) usando un conjunto limitado de datos que consistía en 12 periodos de información de un minuto cada uno, obtenidas en 6 pacientes de intensivo. Un criterio de selección de los pacientes fue que el detector de onda R del ECG pudiese detectar latidos cardíacos correctamente a partir de las ondas. La sensibilidad global y la predictividad positiva para detección de latido fue 94,04 % y 100%, respectivamente. Para identificación de características, la sensibilidad global fue mayor de 89%, la predictividad positiva 100%, y los falsos positivos 0%. Las mediciones pueden haber estado sesgadas por el criterio de selección de pacientes. Esta técnica de identificación de las características de la onda de presión durante BCIA mejora la precisión de las mediciones. La utilidad de usar 2 fuentes de información para mejorar la precisión de las mediciones ha sido así demostrada y debería ser aplicable a otras aplicaciones de procesamiento de señales fisiológicas.

THE PROBLEM

The intra-aortic balloon pump (IABP) is used as a means of temporary mechanical assist for a failing left ventricle [1,2]. During balloon support, clinicians are guided for weaning and assessment of pumping efficacy by some cardiac parameters, e.g., arterial pressure, cardiac index, pulmonary artery (PA) pressure, and pulmonary capillary wedge pressure [1-6]. Although waveform shape and timing information from the pump are typically used by technicians to guide optimal balloon inflation, pressure measurements alone often are used as diagnostic indicators. These pressure measurements often are inaccurate in most cardiovascular monitors [7-9]. Inaccuracies of measured cardiac parameters may be large enough to lead to errors in clinical decisions. We have developed and tested an algorithm that improves arterial blood pressure (BP) measurements during IABP assist. The algorithm correctly extracts clinically important components from arterial BP waveforms: assisted systolic, assisted diastolic, augmented diastolic (also referred to as balloon augmentation), unassisted systolic, and unassisted diastolic pressures. The basis of the algorithm is the integration of two sources of information to correctly differentiate between beats arising from the balloon and the heart. The algorithm was tested using real hemodynamic data.

Background

THE INTRA-AORTIC BALLOON PUMP. An IABP consists of a console that drives a gas flow to a balloon mounted on the tip of a catheter [5]. In IABP therapy, the intra-aortic balloon is placed in the uppermost part of the thoracic descending aorta [1,2,5] (Fig 1). The balloon is alternately inflated and deflated in synchrony with the mechanical phases of the cardiac cycle. The balloon inflation occurs during diastole just after the aortic valve closes, and deflation occurs prior to systole just before the aortic valve opens [1-3,10]. The balloon can be triggered by an electrocardiogram (ECG), pacemaker (atrophicventricular or ventricular) output, an invasive BP, or an internal signal generated at a fixed rate [2,5].

Intra-aortic balloon pump therapy is used to treat several forms of heart disease. It is usually employed for patients who are not responding to medical intervention. Best results are typically achieved in conjunction with cardiac surgery [2,5,11]. It also is applied during coronary arteriography because it increases the safety of this procedure. Intra-aortic balloon pump therapy allows the stabilization of patients who will undergo heart surgery or coronary angioplasty.

HEMODYNAMIC PARAMETER MEASUREMENTS. One of the most important cardiac parameters to monitor during IABP treatment is arterial pressure [1,3,5,12]. Current monitors display the arterial pressure waveform and indicate the associated systolic, diastolic, and mean pressure values. Although these values are meaningful when the pressure signal is unassisted, they may be entirely