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Ejection fractions and pressure–heart rate product to evaluate cardiac efficiency

Continuous, real-time diagnosis using blood pressure and heart rate

(Volume) ejection fractions, defined as the ratio of difference of ventricular volumes prior to and after ejection of blood measures to the ventricular volume prior to ejection, measure the efficiency with which the heart pumps. The American Heart Association recognizes it as a quality indicator in the management of heart failure patients [1]. Universal use of (volume) ejection fraction as a diagnostic tool is limited by the lack of continuous measurements. As the heart must satisfy instant demand, ejection fraction should be measured continuously, in real time, and preferably noninvasively. These conditions can be met, if (pressure) ejection fractions are derived from blood pressure data.

Abbreviations	
HR	heart rate (1/min)
EDV	end-diastolic volume (ml)
ESV	end-systolic volume (ml)
SV = EDV − ESV	stroke volume (ml/beat)
SBP	systolic blood pressure (mmHg)
DBP	diastolic blood pressure (mmHg)
SBP × HR (mmHg/s)	pressure–heart rate product
EF(P) = (SBP − DBP)/ SBP	pressure ejection fraction (%)
EF(P)max	60%—maximal EF(P)
EF(P)min	30%—minimal EF(P)
(SBP x HR)min	115 mmHg/s—minimal pressure–heart rate product

The numerator of the pressure ejection fraction is represented by the pulse pressure. Clinical experience shows that pulse pressure provides information concerning blood flow. In case of an equal arterial mean pressure of 65 mmHg, the peripheral tissue of the extremities will be cold in low pulse pressure of 75/60 mmHg compared with warm skin in higher pulse pressure of 105/50 mmHg, for example.

The pulse wave analysis technology, applied in PiCCO™ and Vigileo-™/FloTrec™, draws flow information from arterial blood pressure. Thus, Ohm's law predicts that the mean arterial pressure and cardiac output are mathematically related; on the other hand, the pulse pressure reflects the pulsatile component of blood pressure [2]. The Vigileo™/FloTrec™ technology is based on the direct proportionality of pulse pressure and stroke volume [3, 4, 5]. As a consequence, the pressure ejection fraction can be viewed as a parameter containing pressure and flow.

Another important parameter is the pressure–heart rate product [6], which is given by the product of systolic pressure and heart rate. The product has been found to be indicative of myocardial oxygen consumption. It can also be measured continuously and non-invasively; thus, it reflects instant status.

The objective of this investigation is to determine whether ejection fractions derived as the ratio of the difference of arterial systolic pressure and arterial diastolic pressure to arterial systolic pressure, pressure–heart rate product, and/or combinations thereof yield useful diagnostic results, which may be obtained non-invasively, continuously, and in real time. A further objective is to demonstrate the possible use of ejection fractions and the pressure–heart rate product to monitor patient safety.

Materials and methods

(Volume) ejection fraction, EF(V) is defined as

$$\mathrm{EF(V)} = \frac{\mathrm{EDV} - \mathrm{ESV}}{\mathrm{EDV}}$$

where EDV is the end-diastolic volume and ESV is the end-systolic volume. In analogy to the definition of EF(V), a (pressure) ejection fraction, EF(P), can be defined as

$$\mathrm{EF(P)} = \frac{\mathrm{SBP} - \mathrm{DBP}}{\mathrm{SBP}}$$

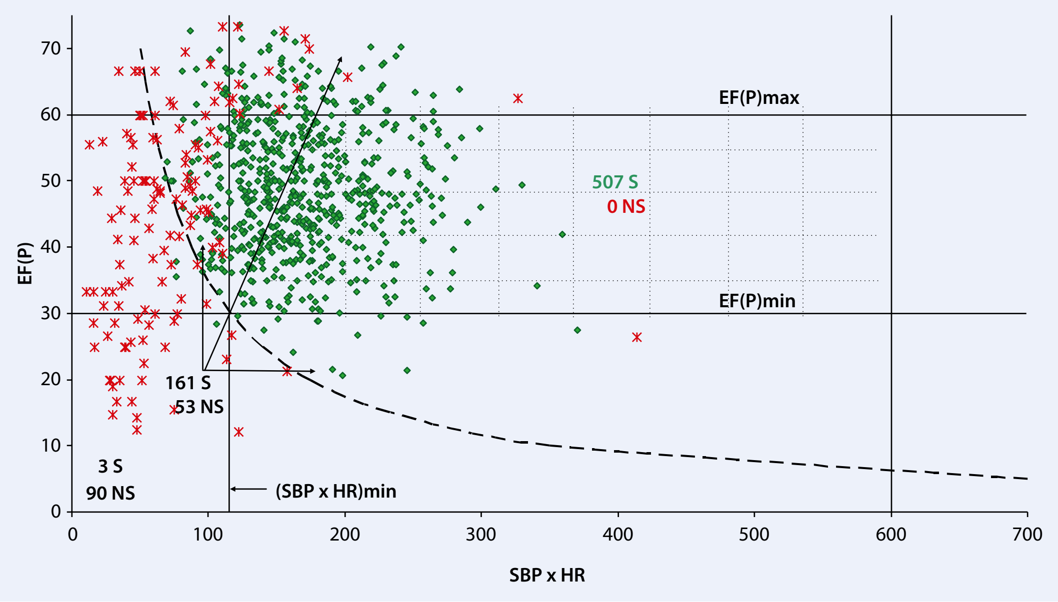

Fig. 1 ▲ Description of the efficiency/pressure–heart product diagram. The diagram displays the efficiency EF(P) as a function of the pressure–heart rate product SBP × HR. *HR* heart rate, *SBP* × *HR* double product. Survivors, *S*, are denoted by the symbol ◊ and non-survivors, *NS*, by the symbol *. Survivors populate exclusively the subarea of the rectangle and non-survivors statistically significant the subarea below the curve. The diagram quantitatively diagnoses improvement for patients transferring from the outside of the survivor rectangle to the inside and for survivors within the survivor rectangle by divergence from the boundary line of the rectangle

where SBP is the arterial systolic pressure and DBP is arterial diastolic pressure. The pressure–heart rate product is defined as SBP × HR and represents myocardial oxygen consumption.

The ICU is an ideal environment to test the universal use of EF(P) and SBP × HR, as survivors and non-survivors with diverse dysfunctions at various stages are treated here. Data measured within 30 min prior to leaving the ICU, whether as survivor or non-survivor, were extracted from charts, then used to determine EF(P) and SBP × HR and subsequently entered into a diagram, where EF(P) is plotted versus SBP × HR, as shown in ■ **Fig. 1**. Survivors are denoted by the symbol ◊ and non-survivors by the symbol *. Selecting the time of 30 min prior to leaving the ICU assured a large diversity of the state of the dysfunctions of the patients.

The co-ordinates of rectangular working area are formed by EF(P) and pressure heart rate. The normal values of blood pressure and heart rate taken from 18-year-old healthy men at rest form the lower borders and the same parameters during maximal effort form the upper borders of the working area. Thus, a working area for the pressure ejection fraction/pressure–heart rate product relationship is defined, within which the patient—in all likelihood—survives.

The cardiocirculatory efficiency (working point) can be evaluated for the moment, for each patient, at any time, and during therapeutic measures. The cardiocirculatory efficiency represents an innovative parameter in various regards. It is based on the pressure ejection fraction and only uses the commonly continuously measured parameters blood pressure and heart rate; it is independent of the patient's illness and is available in real time.

This study was performed on patients in the Department of Intensive Care, Center of Internal Medicine, ICU, of the University of Leipzig. All patients admitted to the ICU in 2008, a total of 824 patients, were eligible for the study. Eighteen patients were excluded for reasons of incomplete data at the required times and ethical considerations such as advanced directives. All patients participating in the study were admitted without regard to any specific dysfunction at the time of admittance to the ICU. No informed consent was obtained from the patients. Anonymity was preserved. The present study is an observational study, using data by reviewing charts of patients, who had already left the hospital at the time of the study. It was performed in accordance with the World Medical Association Declaration of Helsinki [7].

Results

Three distinct areas can be recognized in ■ **Fig. 1**. A rectangle is populated *exclusively* by survivors (507 survivors, 0 non-survivors). This rectangle extends from EF(P)min =30% to EF(P)max =60% and from SBP × HRmin =115 mmHg/s into the outward direction. These markers define the borderlines of the survivor rectangle. Also, a parabola, intersecting at the left lower corner of the rectangle EF(P)min =30% and SBP × HRmin =115 mmHg/s may be drawn. The curve is further defined as an isoplot of all combination of the product of EF and SBP × HR, which yield the same numeral value. The area to left of the curve is populated by non-survivors (90 non-survivors and 3 survivors; *significant*). The curve defines the borderline for non-survivors. A third area, located between the area of the survivors and the area of the non-survivors,

Abstract · Zusammenfassung

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Ejection fractions and pressure–heart rate product to evaluate cardiac efficiency. Continuous, real-time diagnosis using blood pressure and heart rate

Abstract

Introduction. Ejection fractions, derived from ventricular volumes, and double product, related to myocardial oxygen consumption, are important diagnostic parameters, as they describe the efficiency with which oxygen is consumed. Present technology often allows only intermittent determination of physiological status. This deficiency may be overcome if ejection fractions and myocardial oxygen consumption could be determined from continuous blood pressure and heart rate measurements. The purpose of this study is to determine the viability of pressure-derived ejection fractions and pressure–heart rate data in a diverse patient population and the use of ejection fractions to monitor patient safety.

Methods. Volume ejection fractions, derived from ventricular volumes, EF(V), are defined by the ratio of the difference of end-diastolic volume, EDV, and end-systolic volume, ESV, to EDV. In analogy, pressure ejection fraction, EF(P), may be defined by the ratio of the difference of systolic arterial pressure, SBP, and diastolic arterial pressure, DBP, to SBP. The pressure–heart rate (heart rate: HR) is given by the product of systolic pressure and heart rate, SBP × HR. EF(P) and SBP × HR data were derived for all patients (n=824) who were admitted in 2008 to the ICU of a university hospital at the specific time 30 min prior to leaving the ICU whether as survivors or non-survivors. The results are displayed in an efficiency/pressure–heart rate diagram.

Results. The efficiency/pressure–heart rate diagram reveals one subarea populated exclusively by survivors, another subarea populated statistically significant by non-survivors, and a third area shared by survivors and non-survivors.

Discussion and conclusion. The efficiency/pressure–heart rate product relationship may be used as an outcome criterion to assess survival and to noninvasively monitor improvement or deterioration in real time to improve safety in patients with diverse dysfunctions.

Keywords
Hemodynamic monitoring · Patient safety · Blood flow · Pressure-heart rate product · Prognosis

Druckbezogene Auswurfrate und Druck-Frequenz-Produkt zur Bewertung der Herz-Kreislauf-Effizienz. Kontinuierliche Echtzeitdiagnose aus Blutdruck und Herzfrequenz

Zusammenfassung

Einleitung. Auswurffraktion und Druck-Frequenz-Produkt sind Parameter zur Bewertung von Herz-Kreislauf-Effizienz und myokardialem Sauerstoffverbrauch. Die Auswurffraktion ist derzeit nicht kontinuierlich und nur mit technischem Aufwand messbar. Ziel der Studie ist es deshalb, mit einer kontinuierlich gemessenen druckbezogenen Auswurffraktion und der Herzfrequenz die Kreislaufeffizienz in Echtzeit zu bestimmen und den Nutzen für das Patientenmonitoring zu bewerten.

Methode. Die aus dem ventrikulären Volumen ermittelte Auswurfsrate, EF(V), ist definiert als das Verhältnis der Differenz von enddiastolischem Volumen, EDV, und endsystolischem Volumen, ESV, geteilt durch EDV. In Analogie wird eine aus dem Blutdruck ermittelte Auswurfsrate, EF(P), definiert als das Verhältnis der Differenz von systolischem Druck, SBP, und diastolischem Druck, geteilt durch den systolischen Druck. Das Druck-Frequenz(HR)-Produkt ist mit SBP × HR beschrieben. EF(P) und das Druck-Frequenz-Produkt wurde von allen Patienten (n=824) der internistischen Intensivstation des Universitätsklinikums Leipzig aus dem Jahres 2008 bestimmt. Die Mesimmung erfolgte zu einem definierten Zeitpunkt 30 Minuten vor Verlassen der Intensivstation, unabhängig davon, ob der Patient in dieser Zeit verstorben war oder verlegt wurde. Die Ergebnisse sind in einem Effizienz/Druck-Frequenz-Diagramm dargestellt. Referenzbereiche wurden aus den Normalwerten von Blutdruck und Herzfrequenz gesunder Jugendlicher in Ruhe und unter maximaler Belastung gebildet.

Ergebnisse. Im Effizienz/Druck-Frequenz-Diagramm verteilen sich die Patienten auf 3 definierte Areale. Ein Areal enthält ausschließlich Überlebende, ein zweites statistisch signifikant nur Verstorbene und ein drittes statistisch nicht signifikant sowohl Überlebenden als auch Verstorbene.

Diskussion und Schlussfolgerungen. Die Effizienz/Druck-Frequenz-Beziehung eignet sich sowohl als Prognoseparameter zur Beurteilung der Überlebenschancen als auch zur Bewertung des Effekts therapeutischer Interventionen im kontinuierlichen Echtzeitbetrieb und unabhängig von der Grunderkrankung. Sie dient damit der Erhöhung der Patientensicherheit nicht nur auf Intensivstationen.

Schlüsselwörter
Hämodynamisches Monitoring · Patientensicherheit · Blutfluss · Druck-Frequenz-Produkt · Prognoseparameter

was occupied by survivors and non-survivors (161 survivors and 53 non-survivors; *not significant*).

Discussion and conclusion

The results suggest that the combination of pressure ejection fraction and pressure–heart rate product may be a unique addition to present diagnosis in a diverse patient population. Furthermore, benefits are derived from continuous data acquisition of simple, easy to make noninvasive systolic blood pressure, diastolic blood pressure, and heart rate in real time and on-line.

Specifically, the results uniquely suggest the need for immediate interventions for all patients, who are located outside the survival rectangle and very urgently for those, who are situated in the non-survival range left of the parabola to return them into the range for survival. Crossing the borderlines from the inside of the survival range to the outside determines the precise time to commence an intervention, as it indicates deterioration from the survival range into a range of possible no-survival. Crossing the borderline from the outside range to the inside (survival) range reveals improvement. Maintenance of patients in the survival ranges, as quantitatively assessed in real time by EF(P) and SBP × HR, may be used to monitor patient safety. Attainment of the survival range may serve as an outcome criterion.

The working area is independently defined from survivors and non-survivors at the normal values of blood pressure and heart rate from 18-year-old healthy men in rest and under maximal effort. There is a significant separation of survivors and non-survivors by plotting the patient-specific efficiency (working point) into the co-ordinate system 30 min before leaving the intensive care unit, which only shows that the working area represents the field, in which survival is possible. The position of a working point within the working area is the determination of the patient-specific efficiency of the cardiocirculatory system and the efficacy of each therapeutic intervention in the system in real time. These facts prove the actual innovation of using pressure ejection fraction and pressure–heart rate product (cardiocirculatory efficiency).

Further application of this technology to study the effects of specific interventions, e.g., medication, could reveal additional benefits.

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Authors' contributions. HK is a retired theoretical physicist. HK conceived the theoretical concept of pressure ejection determinations. LE is the Chairman of the Department of Intensive Care of the University of Leipzig. LE participated in the design, data collection, and data evaluation and in the critical review of the concept. PT is the Chairman of the Department of Anesthesiology and Critical Care Medicine of the German Heart Center in Munich. He participated in the design, data evaluation, and in the critical review of the concept. All authors read and approved the final manuscript.

Compliance with ethical guidelines

Conflict of interest. H. Kunig, P. Tassani-Press, and L. Engelmann state that there are no conflicts of interest.

The accompanying manuscript does not include studies on humans or animals.

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Fachnachrichten

Hanse-Preis für Intensivmedizin 2014

Auf dem 24. Bremer Symposium für Intensivmedizin u. Intensivpflege sind zwei Wissenschaftler für ihre hervorragenden Studien ausgezeichnet worden.

Priv.-Doz. Dr. Steffen Weber-Carstens, Klinik für Anästhesiologie mit Schwerpunkt operative Intensivmedizin, Universitätsmedizin Berlin, Campus Virchow-Klinikum, erhielt den von der Fresenius-Stiftung Bad Homburg gestifteten Hanse-Preis für seine Arbeit „Critical Illness Myopathy and GLUT4: Significance of Insulin and Muscle Contraction".

Dr. Stefan Bergt, Klinik für Anästhesiologie, Universitätsmedizin Rostock, wurde mit dem Sonderpreis des Wissenschaftlichen Vereins zur Förderung der klinisch angewendeten Forschung in der Intensivmedizin Bremen ausgezeichnet für die Studie „Impact of Toll-Like Receptor 2 Deficiency on Survival and Neurological Function after Cardiac Arrest: A Murine Model of Cardiopulmonary Resuscitation".

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