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The reliability and validity of passive leg raise and fluid bolus to assess fluid responsiveness in spontaneously breathing emergency department patients☆,☆☆

Nicolaj Duus, MD [a,b,*], Daniel J. Shogilev, MD [e], Simon Skibsted, MD, MPH [a,b], Hendrik W. Zijlstra, BSc [a], Emily Fish, MD, MPH [c], Achikam Oren-Grinberg, MD, MS [c], Yotam Lior, BSc [d], Victor Novack, MD, PhD [d], Daniel Talmor, MD, MPH [c], Hans Kirkegaard, MD, PhD [b], Nathan I. Shapiro, MD, MPH [a]

[a] Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, MA
[b] Research Center for Emergency Medicine, Aarhus University Hospital, Aarhus, Denmark
[c] Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, Boston, MA
[d] Clinical Research Center, Soroka University Medical Center Faculty of Health Sciences, Ben-Gurion University of the Negev, Beersheba, Israel
[e] Duke University, Division of Emergency Medicine, Duke University, Durham, North Carolina

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ABSTRACT

Purpose: We investigated the reproducibility of passive leg raise (PLR) and fluid bolus (BOLUS) using the Non-Invasive Cardiac Output Monitor (NICOM; Cheetah Medical, Tel Aviv, Israel) for assessment of fluid responsiveness (FR) in spontaneously breathing emergency department (ED) patients.
Methods: Prospective, observational study of a convenience sample of adult ED patients receiving intravenous fluid bolus. We assessed stroke volume (SV) using NICOM and obtained results from PLR, where the head of the bed was changed from semirecumbent to supine while the patients' legs raised to 45° for 3 minutes. *Fluid bolus* was defined as 5 mL/kg normal saline infusion. Maximal increase in SV was recorded. *Fluid responsiveness* was defined as an increase of SV greater than 10% from baseline. We obtained 4 consecutive responses for each patient; PLR1, PLR2, BOLUS1 separated each by 10 minutes, and BOLUS2 initiated immediately after the end of BOLUS1. We calculated κ statistics, correlation coefficients, and odds ratios with 95% confidence interval and Bland-Altman plots.
Results: We enrolled 109 patients enrolled in this study. The 2 PLRs were significantly correlated ($r = 0.78$, $P < .001$) with $\kappa = 0.46$ for FR ($P < .001$). The 2 BOLUSES less strongly correlated ($r = 0.14$, $P = .001$) and $\kappa = 0.06$ for FR ($P < .001$). Patients who were responsive to PLR1 had 9.5 (3.6-25) odds of being FR for PLR2, whereas those responsive to BOLUS1 had a 1.8 (0.76-4.3) increased odds of FR for BOLUS2.
Conclusion: In conclusion, we have found PLR as measured by the NICOM to be a promising tool for the evaluation of SV responsiveness. It was feasible for use in the ED, and the data suggest that the PLR technique may be more reproducible than the fluid bolus technique for assessing volume responsiveness.

1. Introduction

The primary goal of volume resuscitation is to increase stroke volume (SV) to increase oxygen delivery. Despite technological advances, fluid status assessment in the emergency department (ED) relies primarily on bedside judgment using clinical parameters such as pulse, blood pressure, and urine output. These criteria are all time insensitive and relatively poor indicators of fluid status [1]. Fluid administration requires careful monitoring because both inadequate fluids and fluid overload may worsen outcome [2,3].

Two common methods of providing preload increases to assess responsiveness are fluid boluses or passive leg raise (PLR) [4,5]. The fluid bolus technique is performed by giving a "test bolus" of intravenous (IV) fluids to determine if the heart's SV will increase in response to an increase in preload. If the SV increases during a volume challenge, then physiologically the patient may be classified as being on the ascending part of the Starling curve and will likely further increase SV (and subsequent oxygen delivery) in response to additional IV fluids. Conversely, if the patient is not responsive (does not increase their SV) to a volume challenge, then one may assume that further fluids will not achieve the desired result of increased SV and subsequent cardiac output or oxygen delivery. An alternative method to assess volume responsiveness is to perform a PLR (shift patient position from semirecumbent to a supine position

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* Corresponding author. Tagensvej 94, 3tv, 2200 Copenhagen N, Denmark. Tel.: +45 60234488.
E-mail address: Duus.nicolaj@gmail.com (N. Duus).

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while raising legs to 45°), which returns an estimated 300 cc of blood from the lower extremities to the heart, functioning as an endogenous, reversible preload challenge.

There are several challenges in monitoring patients in the ED because of fast turnover, patient mobility, and the impracticality of invasive monitoring due to the potential adverse effects. There are a number of devices and methods currently available to monitor fluid responsiveness (FR); however transesophageal echocardiography and transthoracic echocardiography are limited by the high user dependency and noncontinuous nature that requires frequent reassessments, whereas more traditional measures like central venous pressure and pulmonary artery occlusion pressures are time consuming, are invasive, and have questionable accuracy [6,7]. The FloTrac-Vigileo™ (Edwards Lifesciences, Irvine, CA, USA), LiDCO (LiDCO Ltd, London, UK), and PiCCO (Pulsion Medical Systems, Munich, Germany) are minimally invasive options that provide user independent continuous dynamic cardiac assessments [8,9]. The Non-Invasive Cardiac Output Monitor (NICOM; Cheetah Medical, Tel Aviv, Israel) is a noninvasive method that provides similar assessments and has shown good results in previous trials [10–12]. Given the potential constraints of the ED setting, we chose the NICOM as our monitoring tool because of feasibility considerations and ease of use in the ED [13,14].

Although studied relatively often in the intensive care unit (ICU), typically in intubated patients, PLR and FR methodologies are relatively less well studied in the ED setting, especially in spontaneously breathing patients [15–17]. Furthermore, we are unaware of a previous investigation that compares reproducibility and accuracy of the 2 techniques of PLR and fluid boluses. The objective of this study is to determine the reproducibility and predictive accuracy of the PLR maneuver and fluid bolus techniques using the NICOM device to monitor FR in a heterogeneous group of ED patients receiving volume resuscitation.

2. Methods and materials

2.1. Study design and population

This was a prospective, observational cohort study of a convenience sample of adult ED patients (age, 18 years or older) who were prescribed IV fluids by the clinical team.

Inclusion criteria are as follows:

1. Age >18 years
2. Clinical team intended to administer IV fluid (of at least 5 mL/kg) as part of treatment

Exclusion criteria are as follows:

1. Acuity precluding participation in research
2. Inability to perform a PLR (eg, lower extremity amputee patients)
3. Inability to obtain consent

Our local institutional review board approved the study, and a verbal informed consent was obtained from each patient before initiating the study.

2.2. Demographics and clinical covariates

We collected demographic variables (age, sex, and race), comorbid disease (chronic obstructive pulmonary disease, chronic heart failure, hypertension, peripheral vascular disease, valvular heart disease, diabetes, coronary artery disease), vital sign information (temperature, blood pressure, heart rate, respiratory rate, and oxygen saturation), the result of laboratory testing (serum lactate, complete blood count, and chemistry panels), and patients' chief complaint, length of stay, and mortality.

2.3. NICOM assessment

All patients were instrumented with the NICOM, which consists of 4 stickers akin to electrocardiogram electrodes being attached to the thorax. The SV is calculated based on an analysis of relative phase shifts and amplitude changes of an oscillating current that passes between the sensors. The phase shifts and amplitude changes are highly correlated with aortic blood volume, thus representing the SV of the heart [14,18]. We performed a PLR and a bolus challenge for all patients. Both tests were performed using the preinstalled programs embedded in the NICOM device. For either test, the baseline consists of placing the patient in a semirecumbent position (head of bed at 45°) for 3 consecutively recorded minutes. For the challenge stage of PLR, the head of the bed was lowered to a supine position and the patient's legs elevated to 45° for 3 minutes (Fig. 1). This maneuver transfers the blood trapped in the lower limbs centrally and increases the preload of the heart similar to a fluid bolus estimated at 300 mL [19]. The fluid bolus test consisted of an infusion of 5 cc/kg crystalloids. The patient remained in a semirecumbent position during fluid infusion. Four consecutive measurements with the NICOM were performed and labeled: PLR1, PLR2, BOLUS1, and BOLUS2. Between PLR1, PLR2, and BOLUS1, there was a 10-minute pause before the next sequence was started to allow the SV to return to baseline; that is, displaced central blood volume returns to lower limbs. BOLUS2 was initiated immediately after the end of BOLUS1 (Fig. 2).

2.4. Outcomes

Fluid responsiveness was defined a priori as an increase in SV greater than 10% from the prechallenge baseline for that particular maneuver. Absolute values of SV were collected for both the prechallenge and challenge stages.

2.5. Data analysis

Means with SDs, medians with interquartile ranges, and proportions were used for descriptive statistics, as appropriate. All test results were analyzed both in a continuous and in a categorical manner. For the categorical analysis, patients were categorized as fluid responsive or nonresponsive with FR defined as an SV increase of 10% or more. For continuous data, we used a Pearson correlation coefficient to define the degree of responsiveness between PLR1 and PLR2 as well as between BOLUS1 and BOLUS2. For agreement between categorical variables, we calculated a Cohen κ. We also constructed 2 $\times$2 tables for PLR1 vs PLR2, PLR2 vs BOLUS1, and BOLUS1 vs BOLUS2; calculated the odds ratios and κ value, along with 95% confidence intervals and Bland-Altman plots; and report the average bias and limits of agreement.

2.6. Sample size assessment

To determine whether passive leg raising and fluid boluses are at least 65% sensitive and specific in detecting a 10% increase in SV, we assumed that the prevalence of responsiveness is 50%. With a point estimate of 80% for both sensitivity and specificity, we estimated that a minimum of 88 patients are required to ensure enough power for the lower bounds of the 95% confidence interval to be above 65%. We

Fig. 1. Illustration of the PLR maneuver.