Clinical examination for diagnosing circulatory shock

Bart Hiemstra, Ruben J. Eck, Frederik Keus, and Iwan C.C. van der Horst

Purpose of review
In the acute setting of circulatory shock, physicians largely depend on clinical examination and basic laboratory values. The daily use of clinical examination for diagnostic purposes contrasts sharp with the limited number of studies. We aim to provide an overview of the diagnostic accuracy of clinical examination in estimating circulatory shock reflected by an inadequate cardiac output (CO).

Recent findings
Recent studies showed poor correlations between CO and mottling, capillary refill time or central-to-peripheral temperature gradients in univariable analyses. The accuracy of physicians to perform an educated guess of CO based on clinical examination lies around 50% and the accuracy for recognizing a low CO is similar. Studies that used predefined clinical profiles composed of several clinical examination signs show more reliable estimations of CO with accuracies ranging from 81 up to 100%.

Summary
Single variables obtained by clinical examination should not be used when estimating CO. Physician’s educated guesses of CO based on unstructured clinical examination are like the ‘flip of a coin’. Structured clinical examination based on combined clinical signs shows the best accuracy. Future studies should focus on using a combination of signs in an unselected population, eventually to educate physicians in estimating CO by using predefined clinical profiles.

Keywords
cardiac output, circulatory shock, clinical examination, critical illness, diagnostic accuracy, physical examination, shock

INTRODUCTION
Many critically ill patients suffer from circulatory shock, which places them at increased risks of multi-organ failure, long-term morbidity and mortality [1,2]. Combinations of clinical, hemodynamic and biochemical variables are recommended for diagnosing shock [3,4].

Daily use of clinical examination (in any patient) for diagnostic purposes contrasts with the limited number of studies, so that the level of evidence in the critically ill is considered best practice [4]. Much remains unknown about the value of clinical examination in diagnosing shock, reflected by an inadequate cardiac output (CO) or maldistribution of blood flow. More knowledge on this topic could assist physicians in the diagnostic process and guide interventions. Previous overviews have evaluated the value of physical examination in sepsis patients [5], cardiovascular patients [6**] and in hemodynamically unstable patients for predicting fluid responsiveness [7*]. We aim to provide an overview of the diagnostic test accuracy of clinical examination findings for estimating CO in critically ill patients.

BACKGROUND
‘Clinical examination’ of the cardiovascular system has been performed for a long time. The first evaluations of heart rate by palpation of the arterial pulse rate date back as far as approximately 335–280 B.C.

Department of Critical Care, University of Groningen, University Medical Center Groningen, Groningen, The Netherlands
Correspondence to Iwan C.C. van der Horst, Department of Critical Care, University of Groningen, University Medical Center Groningen, Hanzeplein 1, P.O. Box 30.001, 9713 GZ Groningen, The Netherlands. Tel: +31 50 361 5617; e-mail: i.c.c.van.der.horst@umcg.nl
Curr Opin Crit Care 2017, 23:293–301
DOI:10.1097/MCC.0000000000000420
This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.
KEY POINTS

- Clinical examination findings are poorly associated with CO in single-variable and multivariable analyses.
- The physician’s accuracy to subjectively estimate CO based on clinical examination equals the flip of a coin.
- Physicians are likely insufficiently capable to recognize a low CO by using clinical examination.
- Estimating CO by using a predefined combination of clinical signs seems the most accurate method to diagnose shock.
- Future studies on estimating CO should be conducted in a representative population, use standardized clinical examination and use appropriate statistical indices of diagnostic accuracy.

Today, PAC has largely been replaced by less-invasive methods for assessment of CO, ranging from echo to pulse pressure analysis devices [23–26].

Despite these technological improvements, clinical examination still holds a prominent position in diagnosing circulatory shock [4,27]. We aimed to provide an overview of the diagnostic accuracy of clinical examination for the assessment of circulatory shock measured by CO or cardiac index (CI). We only included studies that estimated CO using clinical examination based on a one-time snapshot. Physicians mostly use changes in clinical examination findings as proxy for changes in CO to guide their interventions. To evaluate the diagnostic accuracy of changes in clinical examination in relation to changes in CO was beyond the scope of this review. In this review, we were mainly interested which clinical examination findings may accommodate clinical needs, because in daily practice these snapshot measurements guide treatment decisions as triggers for interventions.

METHODS

A sensitive search strategy was used to identify eligible studies (Appendix 1, http://links.lww.com/COCC/A17). In addition, we used the snowball and citation search methods on the selected articles. We attempted to include all studies that provided results on clinical examination findings in relation to CO. We excluded prognostic studies. We separated studies that evaluated univariable associations from studies that used multivariable analyses. Varying statistical indices for describing diagnostic test accuracy as well as a varying prevalence of low CO were encountered, limiting interstudy comparison. Whenever available, we used likelihood ratios as the preferred modality to describe diagnostic accuracy. Likelihood ratios may provide valuable information on disease probability in an individual and do not change with pretest probability (i.e. the prevalence of disease) [28–30]. We calculated sensitivity, specificity, predictive values and likelihood ratios of clinical examination for the detection of low CO whenever possible.

RESULTS

Our search resulted in 8128 hits of which 28 publications were selected. An additional six publications were identified through snowballing. After selection, we included 34 publications in this overview.

UNIVARIABLE STUDIES

Thirteen studies evaluated univariable associations of clinical examination variables with CO, including...
skin temperature or temperature gradients \((n = 8)\) [31–38], capillary refill time (CRT; \(n = 1\)) [39], temperature gradient and CRT \((n = 1)\) [40], motting \((n = 1)\) [41], heart rate and mean arterial pressure \((n = 1)\) [42] and central venous pressure \((n = 1;\) Table 1) [31–43]. The method used for measuring CO varied, including, for example thermodilution with the PAC or Doppler wave with transesophageal or transthoracic echocardiography.

Circulatory shock may lead to compensatory vasoconstriction of nonvital, peripheral tissues such as the skin. Peripheral perfusion can easily be evaluated by measurement of skin temperature, CRT and degree of skin motting. Two studies demonstrated that a subjectively cool skin temperature was associated with a lower CO [31,32]. Studies evaluating the correlation between objective temperature measurements and CO showed conflicting results; some observed moderate correlations [33,35,40], whereas most observed no correlation [34–38]. Skin temperature measurement methods differ widely and are likely influenced by several factors: age, ambient temperature, hypothermia, peripheral vascular disease, vasopressors, pain and anxiety have all been proposed as influencing circumstances [44,45]. This may explain the conflicting results and may limit its usefulness for estimating CO in clinical practice. Several studies have emphasized the prognostic value of prolonged CRT and motting of the skin [39,41,46–49], but only three studies have evaluated their associations with CO and found no relevant correlations [39–41].

Prospective studies on systemic hemodynamic variables showed that heart rate, mean arterial pressure and central venous pressure were not directly correlated to CO [42,43,50]. Only during episodes of deep hypotension, one study observed a moderate correlation between mean arterial pressure and CO [42]. These systemic hemodynamic variables seem to be poor indicators of CO, which supports the common conception that low blood pressure is a late sign of circulatory shock and should not be relied on for early diagnosis [4,51].

**MULTIVARIABLE STUDIES**

Twenty-one studies evaluated multivariable associations of clinical variables with CO. Because of the differing methods of estimating CO, we subdivided our results into studies that evaluated the capacity of physicians to estimate CO \((n = 17;\) Table 2) [13–18, 52–61,62**] and studies that constructed clinical profiles based on multiple variables \((n = 3)\) or a multivariable model \((n = 1)\) to correlate clinical examination findings with CO (Table 3) [63–66]. Furthermore, we could calculate the diagnostic test accuracy for physician’s estimation of low CO in nine studies (Table 2).

**PHYSICIAN’S CAPACITY TO ESTIMATE CO BASED ON CLINICAL EXAMINATION**

Seventeen studies evaluated the accuracy of physician’s estimates or ‘educated guesses’ of CO as compared to objectively measured CO. Estimates were based on clinical examination, with or without knowledge of medical history, biochemical values and/or radiological imaging (Table 2). Some studies used a categorical variable for CO estimates (e.g. ‘low’, ‘normal’ or ‘high’), whereas others used a continuous scale (e.g. 1–12 l per min) [15,17,62**]. Physician’s estimates were correct in 42–62% of the time [13–18,52–61]. Moderate-to-reasonable correlations and a high percentage error were found when physician’s estimates of continuous CO were compared to objectively measured CO [15,16,62**]. Moderate-to-very poor agreements were found in studies that used weighted \(k\) statistics to address agreement occurring by chance [55,59,60,67]. In addition, two studies reported that 21 and 26% of the CO estimations were completely disparate (an estimated high CO when the objective CO was low or vice versa) [55,59].

Nine studies provided enough data for calculation of the diagnostic accuracy of physician’s estimates for detecting low CO. The overall results appeared disappointing [13,14,16,17,53,54,56,58,60] (Table 2). Furthermore, two studies concluded that physicians more frequently overestimated (31–33%) rather than underestimated (18–23%) CO [14,57], implicating that physicians were more prone to miss an insufficient CO. Perel et al. [62**] found the opposite when physicians were asked to estimate CO on a continuous scale.

These results suggest that physicians are not very capable to subjectively estimate CO based on clinical examination. The widely varying diagnostic accuracies are probably the result of different populations or cutoffs for a low CO, but overall it seems that physician’s estimates are ‘an inaccurate diagnostic test’. This is in accordance with two studies of Saugel et al. [67,68], which both demonstrate the incapability of physicians to reliably assess volume status using simple clinical signs. Furthermore, five out of six studies concluded that predictions of senior staff members were equally bad as those of residents or fellows [13,18,54,61,62**,69]. Finally, one study found that the accuracy of estimates was unrelated to the level of confidence physicians had in their assessment [69].

Several important limitations apply. Many studies did not elaborate their methods of clinical
<table>
<thead>
<tr>
<th>Author, year</th>
<th>Patients</th>
<th>Population</th>
<th>Variables of interest</th>
<th>Measurement method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peripheral temperature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaplan et al. 2001 [31]</td>
<td>264</td>
<td>Surgical ICU patients</td>
<td>Temp, subjective: foot ('cool' or 'warm')</td>
<td>PAC, technique not mentioned</td>
<td>'Cool': CI = 2.9 ± 1.2 'Warm': CI = 4.3 ± 1.2</td>
</tr>
<tr>
<td>Schey et al. 2009 [32]</td>
<td>10</td>
<td>Post cardiac surgery</td>
<td>Temp, subjective: foot ('cool' or 'cool-warm' or 'warm') Temp, objective of foot</td>
<td>PAC, thermodilution</td>
<td>'Cool': CO = 3.71 'Cool-warm': CO = 4.83 'Warm': CO = 5.12</td>
</tr>
<tr>
<td>Joly et al. 1969 [33]</td>
<td>100</td>
<td>Circulatory shock</td>
<td>Temp, objective: toe ΔT: toe – ambient (ΔTp-a)</td>
<td>Indicator dilution technique</td>
<td></td>
</tr>
<tr>
<td>Woods et al. 1987 [34]</td>
<td>26</td>
<td>Circulatory shock</td>
<td>ΔT: central – toe (ΔTc-p)</td>
<td>PAC, thermodilution</td>
<td>ΔTc-p: no correlation</td>
</tr>
<tr>
<td>Bailey et al. 1990a [40]</td>
<td>40</td>
<td>Post cardiac surgery</td>
<td>ΔT: central – toe (ΔTc-p)</td>
<td>PAC, thermodilution</td>
<td>ΔTc-p day of operation: no correlation</td>
</tr>
<tr>
<td>Sommers et al. 1995 [36]</td>
<td>21</td>
<td>Post cardiac surgery</td>
<td>Tskin, subjective: axillary, groin, knee, ankle, toe</td>
<td>PAC, thermodilution</td>
<td>ΔTc-p postoperative day: r = 0.60</td>
</tr>
<tr>
<td>Boerma et al. 2008 [37]</td>
<td>35</td>
<td>Sepsis and septic shock</td>
<td>ΔT: central – foot (ΔTc-p)</td>
<td>TEE, Doppler wave</td>
<td>ΔTc-p: r = -0.15</td>
</tr>
<tr>
<td>Bourcier et al. 2016 [38]</td>
<td>103</td>
<td>Sepsis and septic shock</td>
<td>ΔT: toe – ambient (ΔTp-a)</td>
<td>TTE, technique not mentioned</td>
<td>ΔTp-a: no correlation</td>
</tr>
<tr>
<td>Capillary refill time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bailey et al. 1990b [40]</td>
<td>40</td>
<td>Post cardiac surgery</td>
<td>CRT: site not mentioned</td>
<td>PAC, thermodilution</td>
<td>CRT: no correlation</td>
</tr>
<tr>
<td>Skin mottling</td>
<td></td>
<td></td>
<td></td>
<td>TTE, Doppler wave</td>
<td>Mottling score: no correlation</td>
</tr>
<tr>
<td>Ait-Oufella et al. 2011 [41]</td>
<td>60</td>
<td>Septic shock</td>
<td>Mottling score: knee</td>
<td>TTE, Doppler wave</td>
<td></td>
</tr>
<tr>
<td>Systemic hemodynamic variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wo et al. 1993 [42]</td>
<td>256</td>
<td>Severe injury and critically ill postoperative</td>
<td>HR, MAP</td>
<td>PAC, thermodilution</td>
<td>HR: r = 0.27, r² = 0.07, MAP: r = -0.01, r² = 0.0001, MAP during severe hypotension: r = -0.50, r² = 0.25</td>
</tr>
<tr>
<td>Kuntscher et al. 2006 [43]</td>
<td>16</td>
<td>Major burns</td>
<td>Central venous pressure</td>
<td>Thermal dye double indicator dilution</td>
<td>Central venous pressure: r = 0.40</td>
</tr>
</tbody>
</table>

* = repeated measurements in each patient.

b = same study population.

ΔTc-p, central-to-peripheral temperature gradient (°C); ΔTp-a, peripheral-to-ambient temperature gradient (°C); CI, cardiac index (l/min/m²); CO, cardiac output (l/min); CRT, capillary refill time (s); HR, heart rate (beats/min); MAP, mean arterial pressure (mmHg); PAC, pulmonary artery catheter; TEE, transoesophageal echocardiography; Temp, temperature (°C); TTE, transthoracic echocardiography.
<table>
<thead>
<tr>
<th>Author, year</th>
<th>Patients</th>
<th>Setting</th>
<th>Variables of interest</th>
<th>Classification</th>
<th>Estimation base on</th>
<th>Measurement method</th>
<th>Estimation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connors et al. 1983 [13]</td>
<td>62ICU</td>
<td>CI categorical: &lt; 2.5; 2.5–3.5; &gt; 3.5</td>
<td>Clinical assessment, laboratory and X-ray</td>
<td>PAC, thermodilution</td>
<td>44% correct estimation</td>
<td>Sens 58% (45–68%); Spec 60% (48–71%)</td>
<td>LN = 1.43 (1.02–2.00); LR– 0.71 (0.51–0.98)</td>
<td></td>
</tr>
<tr>
<td>Eisenberg et al. 1984 [14]</td>
<td>97ICU</td>
<td>CI categorical: &lt; 4.5; 4.5–7.5; &gt; 7.5</td>
<td>Not described</td>
<td>PAC, thermodilution</td>
<td>51% correct estimation</td>
<td>Sens 71% (54–85%); Spec 56% (42–69%)</td>
<td>LN = 1.64 (1.15–2.33); LR– 0.51 (0.29–0.89)</td>
<td></td>
</tr>
<tr>
<td>Tushmahdi et al. 1987 [15]</td>
<td>35ICU</td>
<td>CI continuous</td>
<td>Clinical assessment and X-ray</td>
<td>PAC, thermodilution</td>
<td>r = 0.72</td>
<td>Sens 49% (0.50–65%); Spec 70% (65–75%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Connors et al. 1990 [17]</td>
<td>461ICU</td>
<td>CI dichotomous: &lt; 2.5; 2.5–4.5</td>
<td>Clinical assessment, laboratory and X-ray</td>
<td>PAC, thermodilution</td>
<td>6.4% correct estimation</td>
<td>Mean Difference in CI = 10 ± 0.9</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Celoria et al. 1990 [16]</td>
<td>114ICU</td>
<td>CI continuous</td>
<td>Clinical assessment, laboratory and X-ray</td>
<td>PAC, thermodilution</td>
<td>51% correct estimation</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Steingrub et al. 1991 [53]</td>
<td>152Surgical ICU</td>
<td>CO categorical: &lt; 4.4–8.8</td>
<td>Clinical assessment, laboratory and X-ray</td>
<td>PAC, thermodilution</td>
<td>51% correct estimation</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Mimoz et al. 1994 [18]</td>
<td>112ICU</td>
<td>Combinations of CI, PAOP and SVRI</td>
<td>Clinical assessment, laboratory, X-ray and echocardiography</td>
<td>PAC, thermodilution</td>
<td>51% correct estimation</td>
<td>Sens 71% (54–85%); Spec 60% (48–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Staudinger et al. 1998 [54]</td>
<td>149ICU</td>
<td>CI categorical: &lt; 2.0; 2.0–4.0; &gt; 4.0</td>
<td>Clinical assessment, medical history, laboratory and X-ray</td>
<td>PAC, thermodilution</td>
<td>62% correct estimation</td>
<td>Sens 71% (54–85%); Spec 60% (48–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Rodriguez et al. 2000 [55]</td>
<td>33ED + respiratory distress or hypotension</td>
<td>CI categorical: &lt; 2.6; 2.6–4.0; &gt; 4.0</td>
<td>Clinical assessment, medical history, laboratory, X-ray and ECG</td>
<td>TEE, Doppler wave</td>
<td>x = 0.04 (95% CI 0.31–0.24)</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.62 (1.28–2.05); LR– 0.73 (0.62–0.87)</td>
</tr>
<tr>
<td>Linton et al. 2002 [56]</td>
<td>50Post cardiac surgery</td>
<td>CI categorical: &lt; 1.9; 1.9–3.5; &gt; 3.5</td>
<td>Not described</td>
<td>LiDCO, indicator dilution</td>
<td>54% correct estimation</td>
<td>Sens 42% (15–72%); Spec 74% (57–87%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.58 (0.67–3.72); LR– 0.79 (0.47–1.32)</td>
</tr>
<tr>
<td>Iregui et al. 2003 [57]</td>
<td>105ICU</td>
<td>CI categorical: &lt; 2.5; 2.5–4.5; &gt; 4.5</td>
<td>Clinical assessment, laboratory and X-ray</td>
<td>TEE, Doppler wave</td>
<td>44% correct estimation</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.58 (0.67–3.72); LR– 0.79 (0.47–1.32)</td>
</tr>
<tr>
<td>Velez et al. 2005 [58]</td>
<td>68ICU</td>
<td>CI categorical: &lt; 2.5; 2.5–4.2; &gt; 4.2</td>
<td>Not described</td>
<td>BioZ, CO monitor, impedance cardiography</td>
<td>42% correct estimation</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.58 (0.67–3.72); LR– 0.79 (0.47–1.32)</td>
</tr>
<tr>
<td>Rodriguez et al. 2006 [59]</td>
<td>31ED + endotracheal intubation</td>
<td>CI categorical: ranges not specified</td>
<td>Clinical assessment, medical history, laboratory and X-ray</td>
<td>TEE, Doppler wave</td>
<td>x = 0.57 (95% CI 0.36–0.77)</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.58 (0.67–3.72); LR– 0.79 (0.47–1.32)</td>
</tr>
<tr>
<td>Nkowak et al. 2011 [60]</td>
<td>38ED + respiratory distress</td>
<td>CO categorical: &lt; 4.0; 4.0–8.0; &gt; 8.0</td>
<td>Clinical assessment and medical history</td>
<td>Neflin, ABP waveform analysis</td>
<td>50% correct estimation</td>
<td>x = 0.02 (95% CI 0.05–0.20)</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
</tr>
<tr>
<td>Duan et al. 2014 [61]</td>
<td>132ICU</td>
<td>CO continuous: &lt; 3; 3–5; &gt; 5</td>
<td>Not described</td>
<td>PiCCO, thermodilution</td>
<td>50% correct estimation</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
<td>LN = 1.58 (0.67–3.72); LR– 0.79 (0.47–1.32)</td>
</tr>
<tr>
<td>Perel et al. 2016 [62, 63]</td>
<td>206ICU</td>
<td>CO continuous</td>
<td>Clinical assessment</td>
<td>PiCCO, thermodilution</td>
<td>Percentage error = 66%</td>
<td>Absolute mean difference in CO = 1.5 ± 2.2</td>
<td>Sens 50% (45–55%); Spec 65% (59–71%)</td>
<td>PPV 43% (38–49%); NPV 74% (71–77%)</td>
</tr>
</tbody>
</table>

**Table 2.** Physician’s capacity to estimate cardiac output based on clinical examination

- **CI:** cardiac index (ml/min/m²);
- **CO:** cardiac output (l/min);
- **ECG:** electrocardiography;
- **ICU:** intensive care unit;
- **LiDCO:** lithium dilution cardiac output;
- **LR–:** negative likelihood ratio;
- **LR+:** positive likelihood ratio;
- **PPV:** positive predictive value;
- **NPV:** negative predictive value;
- **PAC:** pulmonary artery catheter;
- **PAOP:** pulmonary artery occlusion pressure (mmHg);
- **PiCCO:** pulse contour cardiac output;
- **SVRI:** systemic vascular resistance index (dynes s/cm⁵ mm Hg⁻¹);
- **TEE:** transesophageal echocardiography.

---

*repeated measurements in each patient.

**overlapping study populations.

95% CIs, 95% confidence intervals; CI, cardiac index (ml/min/m²); CO, cardiac output (l/min); ECG, electrocardiography; ICU, intensive care unit; LiDCO, lithium dilution cardiac output; LR–, negative likelihood ratio; LR+, positive likelihood ratio; PPV, positive predictive value; NPV, negative predictive value; PAC, pulmonary artery catheter; PAOP, pulmonary artery occlusion pressure (mmHg); PiCCO, pulse contour cardiac output; PPV, positive predictive value; Sens, sensitivity; Spec, specificity; SVRI, systemic vascular resistance index (dynes s/cm⁵ mm Hg⁻¹); TEE, transesophageal echocardiography.
### Table 3. Combined signs of clinical examination for estimation of CO

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Patients</th>
<th>Population</th>
<th>Clinical profile</th>
<th>Clinical profile based on</th>
<th>CO-measurement</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined clinical profiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramo et al. 1970 [63]</td>
<td>98</td>
<td>AMI</td>
<td>I (normal CI): no signs of HF</td>
<td>Mean arterial pressure, cool extremities, urine output, mental status, third heart sound gallop rhythm and rales</td>
<td>PAC, indicator-dilution technique</td>
<td>I (normal CI): 23 of 45 (51%) II (normal CI): 19 of 30 (63%) III (low CI): 10 of 10 (100%) IV (low CI): 13 of 13 (100%)</td>
</tr>
<tr>
<td>Forrester et al. 1977 [64]</td>
<td>200</td>
<td>AMI</td>
<td>I (normal CI): no pulmonary congestion or peripheral hypoperfusion</td>
<td>Heart rate, blood pressure, cool extremities, urine output and mental status</td>
<td>PAC, thermodilution</td>
<td>Overall: 81% correct estimations of CI I &amp; II (normal CI): 84 of 95 (88%) III &amp; IV (low CI): 76 of 105 (72%)</td>
</tr>
<tr>
<td>Grissom et al. 2009 [65]</td>
<td>405</td>
<td>All</td>
<td>I: All three clinical signs aberrant</td>
<td>Capillary refill time, knee mottling and cool extremities</td>
<td>PAC, thermodilution</td>
<td>92% correct estimations of CI in class I: Sens 12% (3–28%); Spec 98% (97–99%) PPV 40% (17–69%); NPV 93% (92–93%) LR+: 7.52 (2.23–25.3); LR– 0.89 (0.79–1.01) 75% correct estimations of CI in class II: Sens 52% (34–69%); Spec 78% (73–82%) PPV 17% (12–23%); NPV 95% (93–96%) LR+: 2.31 (1.58–3.38); LR– 0.62 (0.44–0.89)</td>
</tr>
<tr>
<td>Multivariable analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sasse et al. 1996 [66]</td>
<td>23$^a$</td>
<td>ICU patients</td>
<td>CO continuous</td>
<td>Heart rate, respiratory rate, mean arterial pressure and temperature</td>
<td>PAC, thermodilution</td>
<td>Heart rate: $R^2 = 0.05$ Respiratory rate: $R^2 = 0.14$ Mean arterial pressure: $R^2 = 0.03$</td>
</tr>
</tbody>
</table>

$^a$: repeated measurements in each patient.

ALI, acute lung injury; AMI, acute myocardial infarction; CI, cardiac index (l/min/m²); CO, cardiac output (l/min); HF, heart failure; LR–, negative likelihood ratio; LR+, positive likelihood ratio; NPV, negative predictive value; PAC, pulmonary artery catheter; PPV, positive predictive value; Sens, sensitivity; Spec, specificity.
examination in terms of variables used and definitions employed, leaving variability at the physician's discretion so that these studies cannot be reproduced. PAC was used in most studies, but only in selected patients who failed to respond to initial therapy or in whom clinical examination alone was deemed insufficient, so that evaluation of the accuracy of clinically estimated CO will be biased by definition. Likewise, many other studies also used convenience samples, which hampers generalizability of their results. Clinical examination should be performed in a standardized fashion, according to a protocol, to maximize interobserver agreement and generalizability.

**COMBINED SIGNS OF CLINICAL EXAMINATION FOR ESTIMATION OF CO**

Three studies have compared predefined clinical profiles based upon clinical examination with objectively measured CI (Table 3). Forrester et al. [64] found a good agreement in patients with acute myocardial infarction (AMI). In their study, 75% of patients with low CI and 96% of patients with very low CI had clinical signs of peripheral hypoperfusion, such as decreased skin temperature, confusion or oliguria in conjunction with either arterial hypotension or tachycardia. Ramo et al. [63] observed 100% correct estimation of low CI when patients with AMI had overt signs of pulmonary edema or signs of cardiogenic shock. In their study, clinical signs of overt pulmonary edema were defined by rales or a third heart sound gallop rhythm and cardiogenic shock was diagnosed by the presence of a systolic blood pressure below 90 mmHg, oliguria, cold extremities and disorientation. These findings suggest that physicians can diagnose cardiogenic shock in patients with AMI using clinical examination. Accurate estimation of CO for diagnosing shock in all critically ill patients based on clinical examination might appear much more difficult because of large interindividual differences. Grissom et al. [65] combined CRT, mottling and skin temperature to predict CI in an unselected cohort of patients with acute lung injury. The presence of all three physical signs had a high specificity (98%) but a low sensitivity (12%) for diagnosing shock, suggesting that these three signs accurately rule in, but inaccurately rule out circulatory shock. Varying types of shock are probably associated with varying clinical signs [70], so that a ‘one size fits all’ approach seems inappropriate. Roughly, one-third of all patients with circulatory shock suffer from a low CO, whereas two-thirds have distributive shock with associated high CO [1,71]. Especially in the latter, clinical examination may indicate inadequate circulation regardless of the height of CO and it is difficult to establish how much CO is sufficient for each individual patient.

**PREDICTING CO USING A MULTIVARIABLE MODEL**

One study used multivariable regression analyses to estimate CO based on heart rate, respiratory rate, mean arterial pressure and central temperature (Table 3) [66]. These multivariable results confirm that systemic hemodynamic variables do not correspond well with CO. Future diagnostic studies of CO should therefore incorporate all clinical and hemodynamic variables in a multivariable model.

**CONCLUSION**

Clinical examination findings are poorly associated with CO in single-variable and multivariable analyses. Physicians seem to be insufficiently capable to estimate CO or recognize a low CO using their clinical examination. The most promising results were found when CO was estimated by using predefined profiles composed of combined clinical examination signs. However, most studies were conducted in highly selected populations and the details of estimations were not specified. On the basis of current evidence, using clinical examination to diagnose CO can, to our opinion, not be considered best practice. Future studies on this topic should be conducted in a representative population, use standardized clinical examination and use appropriate statistical indices of diagnostic accuracy. Ultimately, these results should guide education of physicians to estimate CO using predefined clinical profiles.

**Acknowledgements**

None.

**Financial support and sponsorship**

None.

**Conflicts of interest**

There are no conflicts of interest.

**REFERENCES AND RECOMMENDED READING**

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Cardiovascular system


7. This review extensively elaborates the diagnostic accuracy of physical examination of the cardiovascular system.


9. This review provides a comprehensive overview of studies that measure hypo-lemia.


This large multicenter study included a broad ICU cohort and used sophisticated statistical measures to correlate CO to clinical examination.


