Background Accurate measurements for determining cardiac index can be obtained while patients are supine in bed at various backrest elevations. It is not clear if these measurements are accurate when patients are in a bedside chair.

Objective To determine if cardiac index based on measurements obtained with the patient in a chair is similar to cardiac index based on measurements obtained with the patient in bed.

Methods A convenience sample of cardiac surgical patients and a method-comparison design were used to compare cardiac index values based on measurements obtained with patients in 2 different positions: in a chair and in the bed. A standard thermodilution technique was used to measure cardiac output. Measurement of cardiac output in the second position was obtained immediately after measurement in the first position. Positions were randomly assigned. Bias and precision were calculated and graphed with the Bland-Altman method. Differences in cardiac index of 0.50 or more were considered clinically significant. Analysis of variance was used to determine differences between cardiac index values for the 2 positions.

Results A total of 27 postoperative cardiac surgical patients were studied. Cardiac index values based on measurements obtained with patients in the 2 different positions did not differ significantly ($F_{1,50} = 0.446; P = .51$). The mean difference score (bias) between the 2 positions was -0.07 (precision, 0.30)

Conclusions The practice of putting cardiac surgical patients whose hemodynamic status is stable back to bed before obtaining measurements for calculation of cardiac index may not be required for accurate values. (American Journal of Critical Care. 2011;12:210-216)
Several factors affect the accuracy of cardiac index (CI; calculated as cardiac output in liters per minute divided by body surface area in square meters) values based on measurements obtained by using the thermodilution method, including the volume and temperature of the fluid used for the injection, the speed and smoothness of the injection technique, and the position (side lying) of the patient.\textsuperscript{1-4} In previous research\textsuperscript{5-7} on the effects of positioning, differences in CI values based on measurements obtained with patients in the supine position with elevation of the head of the bed (HOB) from 0° to 45° were small and clinically insignificant.

Although accurate CI values can be obtained while a patient is supine in bed at various HOB elevations, the accuracy of CI values based on measurements obtained when a patient is sitting in a bedside chair is not known. Compared with the supine position in bed with the HOB elevated, sitting in a bedside chair is a more upright upper body posture, with more lower extremity dependency and knee and hip flexion. This difference in posture could create differences in blood flow and/or cardiac output. To date, no investigators have examined whether the CI values based on measurements obtained when a patient is sitting in a chair are similar to the values based on measurements obtained when a patient is in bed in a supine position. Consequently, clinicians must either put patients back in bed before obtaining measurements for calculating CI or delay obtaining these important measurements.

The purpose of this study was to determine if CI values based on measurements obtained in a bedside chair are similar to those based on measurements obtained in bed in cardiac surgical patients in stable condition.

**Materials and Methods**

The study was conducted in an 18-bed cardiovascular intensive care unit at Saint Luke’s Hospital, Kansas City, Missouri, a 564-bed community-based hospital. Study approval was obtained from the institution’s investigational review board before data were collected.

**Study Design**

A method-comparison design was used to compare CI values based on measurements obtained in 2 different body positions: supine in bed and sitting in a bedside chair. Each patient served as his or her own control. The dependent variable was the CI value. Patients were assigned to treatment order by use of a computer-generated random number sequencer. Investigators had no knowledge of the group assignments until after the patients were enrolled in the study.

**Sample Selection**

The sample consisted of postoperative, adult cardiothoracic surgery patients. Patients were included if they had had coronary artery bypass grafting, aortic or mitral valve surgery, ascending thoracic aorta repair, and/or ventricular septal defect repair; had the physical ability to transfer out of bed; had a pulmonary artery catheter in the correct position; and had had no active titration of vasoactive medications for 10 minutes before and during the data collection period. Exclusion criteria included medical contraindication to getting out of bed; mechanical ventilation; unstable hemodynamic status (CI <2.0, mean arterial pressure 60 mm Hg or less or 85 mm Hg or greater, heart rate less than 60/min or greater than 140/min, or change in cardiac rhythm for 30 minutes before and during the data collection period); medical history of moderate to severe tricuspid regurgitation; or chest tube drainage of 100 mL or more within the previous hour.

Sample size was based on an a priori power analysis for the $F$ test, with an effect size of 0.58, power of 80%, and $\alpha = .05$.\textsuperscript{9} Effect size was calculated to identify a mean difference between CI values for the 2 positions of at least 0.50, assuming a standard
Standard deviations for the sample size calculation were based on data from a previous study on the CI. The calculations indicated that a minimum of 26 patients was needed for hypothesis testing.

**Operational Definitions**

Definitions of the variables in the study are as follows:

- In-bed position: supine position, in bed (Epic II, Critical Care Bed, model 2040, Stryker, Portage, Michigan) with the HOB elevated 30° (Figure 1A).
- Chair position: sitting position, out of bed in a nonreclining, straight-back chair in the upright position with knees bent and feet on the floor (Figure 1B).
- Cardiac index: based on measurements of cardiac output obtained with the thermodilution technique according to the manufacturer’s instructions with a pulmonary artery catheter (Thermodilution Catheter, Heparin-Coated Pentalumen 8F, 5 lumen, 110 cm, Hospira, Lake Forest, Illinois) and a room-temperature injectate delivery system (Thermostet Room Temperature Closed Loop Injectable Delivery System With In-Line Temperature Probe, Hospira) connected to a cardiac output computer module (Philips CMS monitor model M1046 and cardiac output module model M1012A, Philips Medical Systems, Andover, Massachusetts). Injectate volumes of 10 mL were used for all measurements for determination of CI.

**Study Procedure**

Data were collected by study investigators trained in proper techniques for measurement of cardiac output, determination of CI, and all study procedures before patients were enrolled in the study. All thermodilution measurements were obtained according to the following procedures:

1. Positioning of the pulmonary artery catheter was confirmed by observation of the pulmonary artery waveform on the bedside monitor.
2. The appropriate computation constant for catheter size/type was input into the cardiac output module.
3. Up to 4 boluses (10 mL each at room temperature) of injectate were administered through the proximal port of the pulmonary artery catheter, when prompted by the cardiac output program, until 3 cardiac output values were obtained within 10% of the median value of the outputs.
4. The mean CI value displayed on the cardiac output module was recorded. If more than 4 injectate boluses were required to determine the mean, the CI was recorded as “unobtainable.” Cardiac out-

![Figure 1](positions_used_to_determine_cardiac_index.jpg)

Figure 1 Positions used to determine cardiac index. A, Supine, in bed with the head of the bed elevated to 30°. B, Chair, in the upright position with feet placed flat on the floor.
Data Analysis

Data were summarized by using descriptive statistics. Analysis of variance was used to determine if CI values differed with position and/or order of positioning. Mean difference scores (bias) and limits of agreement (precision) between the 2 CI position values were calculated and graphed by using the Bland-Altman method. The level of significance for all tests was \( P < .05 \).

Results

A total of 27 patients had CI determined on the basis of measurements obtained in 2 positions: supine in bed and in a bedside chair. Patient characteristic data are summarized in the Table. The majority of patients were men, and coronary artery bypass grafting was the most common surgical procedure. Age, sex, body temperature, type of surgical procedure, and types of vasoactive intravenous infusions during data collection were similar for patients assigned to different treatment orders (in-bed and chair position sequences).

The range of CI values was 2.04 to 3.43, with means of 2.70 (SD, 0.37) and 2.63 (SD, 0.36) for in-bed and chair measurements, respectively. CI values did not differ significantly for thermodilution measurements obtained in the 2 different body positions \( (F_{1,50} = 0.446; P = .51) \) and in different treatment order \( (F_{1,50} = 1.154; P = .29) \).

The range of CI difference scores between the 2 positions was -0.47 to 0.56 (mean bias, -0.07; precision, 0.30). Only 1 of the 27 patients had an absolute difference score of 0.50 or more: difference score, 0.56; CI, 2.51 (SD, 3.07) for in-bed and chair positions. Individual difference scores between measurements obtained in the 2 positions, as well as the mean difference score (bias), are depicted in Figure 2 according to the method of Bland and Altman.

Discussion

Differences between CI values based on thermodilution measurements of cardiac output obtained in a chair and in bed were small and statistically insignificant. Only 1 of the 27 patients had an absolute difference of 0.50 or more, and all CI differences between the 2 positions were less than 0.60. This study is the first to show that the clinical practice of putting cardiac surgical patients whose hemodynamic status is stable back in bed before obtaining measurements for CI may not be required to obtain accurate CI values.

Whereas previous studies have addressed the effect of changes in positioning (HOB elevation; sidelying position) on the accuracy of CI values based on thermodilution measurements, our study is the first in which the results for in-bed and chair positions were compared. In earlier studies, in critically ill patients, CI values based on measurements obtained with patients in the supine position did not differ when the HOB was elevated from 0° up to 45°. In the only studies in which the effects of HOB elevations greater than 30° were examined, differences

Stable post-operative cardiac surgical patients do not need to be placed in bed just to obtain a cardiac index.

In chair position, the patient sits upright in a non-reclining, straight-back chair with knees bent and feet on the floor.
positions were compared with those of side-lying positions, the results were mixed; in 1 study, no clinical differences between the 2 positions were detected, whereas in the other study, a significant difference was found. Although the reason for the differing results in studies is not known, experts recommend that the side-lying position not be used when obtaining measurements for determination of CI.

In light of the mixed results in comparison studies with HOB elevations greater than 30º and the side-lying position, one could hypothesize that measurements of cardiac output for calculation of CI obtained with patients sitting in a beside chair could be inaccurate. Our results, however, do not support that hypothesis in cardiovascular surgery patients in stable condition. Differences between in-bed and in-chair CI values were clinically and statistically nonsignificant; only 1 patient had a CI difference between the 2 positions of 0.50 or greater.

The clinical implications of these results are that postoperative cardiac surgical patients in stable condition who are sitting in a chair do not need to be placed back in bed just to obtain a routine car-

Table
Demographic data for 27 postoperative cardiac surgical patients with cardiac index determined with patient in 2 positions (supine, in bed with the head of the bed elevated to 30º; chair in the upright position with feet placed flat on the floor)\(^a\)

<table>
<thead>
<tr>
<th>Variable</th>
<th>In bed first, chair second</th>
<th>Chair first, in bed second</th>
<th>All participants (N = 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>65.1 (13.1)</td>
<td>67.2 (9.8)</td>
<td>66.3 (11.5)</td>
</tr>
<tr>
<td>Sex, male/female</td>
<td>11/3</td>
<td>8/5</td>
<td>19/8</td>
</tr>
<tr>
<td>Body temperature, mean (SD), ºC</td>
<td>37.3 (0.5)</td>
<td>37.5 (0.4)</td>
<td>37.4 (0.5)</td>
</tr>
<tr>
<td>Surgical procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABG only</td>
<td>9</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>CABG + AVR</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>CABG + MVR</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>AVR only</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>MVR only</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Vasoactive intravenous infusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dobutamine</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Dopamine &gt;3 μg/kg</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Milrinone</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Norepinephrine</td>
<td>9</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\) Values are number of patients unless otherwise indicated. Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass graft; MVR, mitral valve replacement.
Limitations

Several limitations in this study limit the generalizability of the findings. First, we evaluated only the thermodilution technique for determining CI, so whether similar results would be obtained with a continuous cardiac output method is not known. Also, the CI values in our study were relatively normal values. Whether results would be similar in patients with abnormally low or high CI states is not known. In addition, our sample was restricted to postoperative cardiac surgical patients in stable hemodynamic condition who were not receiving mechanical ventilation. Although patients in an unstable condition probably would not be out of bed, if a patient’s hemodynamic condition become unstable while the patient were out of bed, clinicians should not assume that cardiac output measurements obtained in that situation yield accurate CI values.

Our results need to be validated in a variety of populations of critically ill patients. A special area of importance is evaluation of the chair position in patients receiving mechanical ventilation to determine if changes in intrathoracic pressure associated with mechanical ventilation affect the accuracy of CI values. Studies should also be done with continuous cardiac output methods and with patients seated in the chair position available in some critical care beds.

Conclusions

We found that the difference between CI values based on measurements of cardiac output obtained in bed and in a bedside chair were small and statistically insignificant in 27 cardiac surgical patients. This study is the first to be published in which in-bed measurements are compared with chair measurements for calculation of CI values, and we found that the clinical practice of putting cardiac surgical patients in stable hemodynamic condition back in bed before obtaining measurements for determination of CI may not be required to obtain accurate CI values.

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REFERENCES


To purchase electronic or print reprints, contact The InnoVision Group, 101 Columbia, Aliso Viejo, CA 92656. Phone, (800) 899-1712 or (949) 362-2050 (ext 532); fax, (949) 362-2049; e-mail, reprints@aacn.org.
1. The formula for cardiac index (CI) calculation is which of the following?
   a. Cardiac output in liters per minute multiplied by body surface area in square meters
   b. Cardiac output in liters per minute divided by body surface area in meters cubed
   c. Cardiac output in liters per minute divided by body surface area in square meters
   d. Cardiac output in liters per hour multiplied by body surface area in square meters

2. Patients were included in the study if they had experienced which of the following?
   a. CI less than 2.0
   b. Coronary bypass grafting
   c. Heart rates greater than 140/min or less than 60/min
   d. More than 100 mL of chest tube drainage in the last hour

3. Which of the following criteria was used to decide which patients would be excluded from the study?
   a. Aortic or mitral valve surgery
   b. Unstable hemodynamic status
   c. The physical ability to get up to the chair
   d. Having had no vasoactive drugs titrated within 10 minutes

4. CI measurements in the bed were obtained from patients in which of the following positions?
   a. On the left side
   b. In high Fowler’s position
   c. With head of bed (HOB) at 30°
   d. With HOB at 45°

5. The chair position for the patients included which of the following?
   a. Using a recliner to change angles and keep feet off the floor
   b. Using a straight-back chair with the patient’s legs extended outward
   c. Using a straight-back chair with 2 pillows behind the back to reach the floor
   d. Using a straight-back chair with knees bent and feet on the floor

6. Which of the following describes the method by which the CI calculation was obtained?
   a. Visual observance of the cardiac output curve
   b. Averaging 4 boluses of iced injectate
   c. Obtained within 5 minutes of each position change
   d. Verified by a second nurse prior to being accepted

7. The level of statistical significance for the differences in CI value scores was which of the following?
   a. \( P > .05 \)
   b. \( P = .05 \)
   c. \( P < .05 \)
   d. \( P-P_1 > .05 \)

8. In studies in which the effects of HOB elevation greater than 30° were examined, the differences between CI values for supine HOB elevations of 0° and 45° were which of the following?
   a. Found to be not statistically different
   b. Found to be statistically significant
   c. Determined to have mixed results
   d. Not attempted due to patient condition

9. Limitations of the study included which of the following?
   a. Only stable cardiac arrest patients were included.
   b. Only stable postoperative cardiac surgery patients were included.
   c. Only patients with high CI values were included.
   d. Patients were chosen from mixed cardiac surgery procedures.

10. Most patients in the study had which of the following conditions?
    a. Cardiac output in liters per minute multiplied by body surface area in square meters
    b. Coronary artery bypass grafting only
    c. Coronary artery bypass with mitral valve replacement
    d. Mitral valve replacement only

11. This study noted which of the following as a clinical advantage to leaving a patient in the chair during CI measurements?
    a. Less caregiver strain
    b. The ability to assess CI at mealtime
    c. Improved patient pulmonary status
    d. Straight-back chairs are easier to obtain than recliners for postoperative patients

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