Notice to CNE enrollees:
A closed-book, multiple-choice examination following this article tests your understanding of the following objectives:

1. Identify hemodynamic changes that occur with manual repositioning.
2. Discuss hemodynamic changes that occur with continuous rotation.
3. Determine if use of manual or automatic turning is safe for medical-surgical patients receiving mechanical ventilation.

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Background  Lateral turning of critical care patients receiving mechanical ventilation can adversely affect hemodynamic status.
Objective  To study hemodynamic responses to lateral turning.
Method  A time-series design with automated signal processing and ensemble averaging was used to evaluate changes in heart rate, mean arterial pressure, and pulse pressure due to lateral turning in 13 adult medical-surgical critical care patients receiving mechanical ventilation. Patients were randomly assigned to the manual-turn or the automated-turn protocol for up to 7 consecutive days. Heart rate and arterial pressure were measured every 6 seconds for more than 24 hours, and pulse pressure was computed.

Results  A total of 6 manual-turn patients and 7 automated-turn patients completed the study. Statistically significant changes in heart rate, mean arterial pressure, and pulse pressure occurred with the manual turn. Return of the hemodynamic variables to baseline values required up to 45 minutes in the manual-turn patients (expected recovery time ≤ 5 minutes). However, clinically important changes dissipated within 15 minutes of the lateral turn. The steady-state heart rate response on the right side was slightly greater (3 beats per minute) than that on the back (P = .003). Automated turning resulted in no clinically important changes in any of the 3 variables.

Conclusions  In medical-surgical critical care patients receiving mechanical ventilation, manual lateral turning was associated with changes in heart rate, mean arterial pressure, and pulse pressure that persisted up to 45 minutes. (American Journal of Critical Care. 2015;24:131-140)
Critically ill patients treated with mechanical ventilation are at high risk for preventable pulmonary complications. A standard of care to reduce complications is lateral turning every 2 hours. Lateral turning of intensive care patients receiving mechanical ventilation can adversely affect hemodynamic status.5,6 Although the adverse effects are typically transient,1,4 clinicians may be reluctant to laterally position critically ill patients who are receiving mechanical ventilation.

Positive-pressure ventilation can reduce venous return3 and cardiac output.6,7 Lateral turning may augment adverse hemodynamic effects in patients receiving mechanical ventilation. A decrease in blood pressure in the lateral position, compared with the back position, has been reported.5,8 Gawlinski and Dracup10 found that blood pressure returned to baseline values within 5 minutes of a turn, suggesting that lateral turning has a transient effect. Because factors that cause decreased venous return would be maintained throughout the time spent in the lateral position, transient effects on blood pressure suggest that the changes are either responses involved in hemodynamic compensation or responses to the physical act of turning and not to the lateral position per se.

Research on the hemodynamic effects of lateral turning has been limited by the use of discrete measurements (eg, ≤ 5 time points in each lateral position) and short study duration. The hemodynamic effects of automated turning have not been systematically evaluated. We conducted a randomized clinical trial as a pilot study to compare the efficacy for preventing and treating pulmonary complications and the safety of 2 turning interventions (www.ClinicalTrials.gov: NCT00542321): manual turning every 2 hours (standard of care and control group) and continuous automated turning with a kinetic therapy bed (experimental group). As a component of the safety assessment, we examined turning-related hemodynamic responses, defined as changes in heart rate, mean arterial pressure (MAP), and pulse pressure.

Materials and Methods

A time-series design with automated signal processing and ensemble-averaging was used to measure heart rate, systolic blood pressure (SBP), diastolic blood pressure (DBP), and MAP every 6 seconds for more than 24 hours. The research protocol was approved by the appropriate institutional review boards at the University of Texas Health Science Center at Houston and the 2 participating hospitals. The 13 eligible adult patients recruited for the study were assessed for hemodynamic response to manual or automated turning.

Interventions

The manual-turning protocol included a lateral turn of 45º or greater every 2 hours for a duration of 2 hours. Research nurses turned patients to the lateral position, ensuring that the patients’ proper body alignment was maintained with the lower leg in extension and the upper leg and upper limbs flexed. Pillows were placed between each patient’s thighs, shins, and arms for comfort. Adherence to the protocol was assessed every 10 minutes.

The TriaDyne Proventa bed (ArjoHuntleigh) was used for automated turning. The automated-turning protocol included continuous rotation with lateral rotation to an angle of 40º or greater. Research nurses measured the maximum angle achieved and the direction of turn every hour.

Study Procedures

General study procedures, including random selection and assignment, have been reported elsewhere.11 Hemodynamic data were obtained with a
physiological monitor (HP Component Monitoring System, Philips Medical Systems, or Solar 8000i, GE Healthcare) and an arterial catheter pressure transducer (Edwards Lifesciences, PX600F or PX284). Heart rate and blood pressure data from the HP system were directly transferred via an RS232 serial interface to a laptop computer by using a custom-written software application in the LabView programming environment (National Instruments). Heart rate, SBP, DBP, and MAP were downloaded every second with date and time stamp and were aggregated in sequential 6-second means. For the Solar monitor, BedMaster (version 1.3, Excel Medical Electronics) software was used to communicate with the hospital’s Unity Network (General Electric/Marquette) to obtain the data. Pulse pressure was calculated as SBP minus DBP.

In order to account for hydrostatic-pressure effects related to changes in the height of the pressure transducer with continuous rotation, a correction formula for MAP was applied, as reported elsewhere. The height-adjustment correction was not applied to pulse pressure because this variable is the difference between SBP and DBP, 2 quantities that are equally affected by the changes in height. Pulse pressure therefore reflects a difference that is independent of the height of the transducer.

**Data Management and Analysis**

SPSS (version 17.0, SPSS Inc) and TIBCO Spotfire S+ (version 8.1, TIBCO Software Inc) software programs were used for data management and analyses. Outliers, defined as data points 3 or more standard deviations from the mean, and missing data were replaced by using linear interpolation.

Ensemble averaging, adjusted for autocorrelated data, was used to assess within-subject hemodynamic responses to turning. Heart rate, MAP, and pulse pressure were evaluated for graphical characteristics of increase or decrease with the manual turn and 95% CI overlap with the automated turn; statistical significance; clinical importance; and, in the manual-turn group, recovery time, defined as length of time for the value to return to baseline. A change in heart rate of more than 10 beats per minute, changes in MAP and pulse pressure of 10 mm Hg or greater, and 5 minutes or more for recovery were determined a priori as clinically important changes.

For the manual-turn patients, heart rate, MAP, and pulse pressure data were segregated into 4 turn categories: back to left, left to back, back to right, and right to back. Data for each turn category were averaged in 12-second bins (aggregated data) to reduce high autocorrelation in the data, starting 15 minutes before the turn (preturn period) and ending 45 minutes after the turn (postturn period). The first 5 minutes of the preturn period was considered the baseline interval. Starting at the end of the baseline interval, data intervals of 5-minutes duration were compared statistically with the baseline interval, moving forward in 1-minute increments to define each subsequent test interval. The mean values of the baseline interval and each test interval were compared by using a generalized least-squares model with a first-order autoregression parameter to account for the correlated nature of the data at each interval. By using the ensemble averages for each variable, a patient’s maximum magnitude of change was identified on the basis of statistically significant differences from the preturn baseline in the postturn data.

Because of the continuous, slow turning for the automated-turn patients, a different approach was used. Heart rate, MAP, and pulse pressure data were segregated into 10º angle bins (aggregated data) that were distinguished by direction of movement so that a picture of the entire 12-minute rotation cycle could be obtained. Bin angles from -10º to 10º were considered the back position. The left position corresponded to angles less than -10º and the right position to angles greater than 10º. The last bin on each side was an “open” bin due to variable maximum angles obtained with the automated bed (±30º to ±60º) for a total of 8 angle bins. Because large numbers of turns were available for automated turning, the ensemble average in each angle bin was computed according to a longitudinal mixed-effects model with random intercept for the turns and first-order autoregressive structure.

At the across-subjects level, 2-way analysis of variance was used to compare changes in heart rate, MAP, and pulse pressure between turn groups and back-to-right and back-to-left positions. Mean values were determined for each turn direction (manual-turn group) or angular bin (automated-turn group). In the automated-turn group, angle bins in the back position were combined and then compared separately with angle bins in the left and right positions. The 95% CI of the overall mean was an estimate of the variability.

**Results**

The study consisted of 6 patients (46%) randomly assigned to the manual-turn group and 7 patients (54%) randomly assigned to the automated-turn group. Patients’ demographic and clinical
characteristics did not differ significantly between the 2 groups (Table 1). Data collection time varied from 27.1 to 165.2 hours. Heart rate data were collected for all patients, and blood pressure data were collected for the 7 patients (54%) who had an arterial catheter placed for clinical purposes.

Standardized residuals were less than or equal to ±2 for all hemodynamic variables, suggesting normal distribution of the data. The length-of-time series data used in the analysis for each patient varied from 16,247 to 99,095 data points, representing a mean of 79.2 (SD, 51.3) hours for the manual-turn and 74.9 (SD, 55.7) hours for the automated-turn group (P = .88). Combined outlier and missing values represented 3.4% or less of the data. For the manual-turn group, turning was maintained for 94% of the time patients were on protocol, and mean turn angle was 50° (SD, 5°); for the automated-turn group, these values were 91% and 32° (SD, 3°), respectively. Mean turn angle differed significantly between groups (P = .003). Within-subject mean changes in heart rate, MAP, and pulse pressure across all turns for the manual- and automated-turn groups are presented in Figure 1. Postturn recovery time (manual-turn group only) is presented in Table 2.

### Ensemble Averages of the Manual-Turn Group
Manual lateral turning induced changes in heart rate, MAP, and pulse pressure. Figure 2 shows individual turn data and ensemble-averaged data for patient P001 as an example. Graphical displays of the data show hemodynamic responses to turning both in the individual turns (Figure 2, panels A, B, and C) and ensemble-averaged data (Figure 2, panels D, E, and F). Clinically important changes in heart rate were detected in 2 patients in the left position and in 2 patients in the right position. With the exception of 1 patient in the back-to-left position, all patients showed a prolonged, statistically significant recovery time in heart rate from 9 to 45 or more minutes after turning (Table 2); clinically important changes (heart rate, ±10 beats per minute) were transient and dissipated within 15 minutes of the turn. The same was true for MAP and pulse pressure recovery times.

Of the 4 manual-turn patients who had an arterial catheter, 2 had statistically and clinically significant increases in MAP with a change in position that varied from +13 to +22 mm Hg (Figure 1B). Magnitude of change did not differ between back-to-left (+22 mm Hg) and back-to-right (+21 mm Hg) lateral turning. Three patients had prolonged MAP recovery time that varied from 9 to 37 or more minutes (Table 2). A total of 4 patients had statistically significant changes in pulse pressure associated with manual turning: 3 had an increase and 1 had a decrease, but only 1 of the changes was a clinically important change, with the greatest magnitude of +23 mm Hg in the back-to-left position. Three patients had prolonged pulse pressure recovery time of up to 43 minutes (Table 2).

### Ensemble Averages for the Automated-Turn Group
Automated turning induced changes in heart rate, MAP, and pulse pressure (Figures 3A, 3B, and 3C). Among the 7 patients, 3 (43%) had a statistically significant heart rate response to left and right
turning compared with the back position. However, the changes were not clinically important; the maximum response was a change in heart rate of 2 beats per minute compared with the back position. All 3 automated-turn group patients with an arterial catheter had a statistically significant decrease in MAP when turned to the left and right positions compared with the back position; the magnitude of response varied from -4 to -9 mm Hg. With the height-adjusted model, MAP differences were 1 mm Hg or less. Two patients had a statistically significant change in pulse pressure in both the left and right positions compared with the back position. The changes were not clinically important; the maximum response was 5 mm Hg or less (Figure 3C). Because the patients were in constant motion, recovery time could not be calculated.

**Group Comparisons**

The change in heart rate for the manual-turn group was significantly greater in the right lateral than in the back position \((P = .003)\); the mean change of +3 beats per minute was not clinically important. No other within-group differences in position or position by group interaction were significant. Between-group differences in heart rate, MAP, and pulse pressure were not significant.

**Power Computation**

Power calculations with \( \alpha = .05 \) showed that the study was adequately powered (>89%) to detect within- and between-group clinically important changes in heart rate and MAP and within-group changes in pulse pressure, but not clinically important changes in pulse pressure between turning-intervention groups.

**Discussion**

In this study of manual vs automated turning, statistically significant changes occurred in heart rate, MAP, and pulse pressure with manual turning. The heart rate and MAP changes were clinically important in 50% and 25% of patients, respectively, in this small study sample. These findings may reflect the higher mean scores on the Acute Physiology and Chronic Health Evaluation II and the greater percentage of patients with vasopressor support in the manual-turn group, despite random selection and assignment of patients. The times for the hemodynamic parameters to return to baseline values were highly variable: in some patients, heart rate did not recover to baseline within the observation period of 45 minutes after a turn. All patients with an arterial catheter in the automated-turn group

![Figure 1](http://www.ajcconline.org)
All patients in this trial tolerated lateral turning.

had a statistically significant change in MAP and all but 1 had a significant change in pulse pressure in the lateral position. However, less than half of the automated-turn group had a statistically significant change in heart rate, and none of the hemodynamic changes was clinically important. Furthermore, the MAP differences were not statistically significant in the height-adjusted model. Thus, automated turning does not appear to adversely affect hemodynamic status and may be the preferred turning intervention when patients are at risk for unstable hemodynamic status.

The differences in hemodynamic responses we found between manual and automated turning may be due to the angle of turn, which was greater in the manual-turn group. On the basis of the literature, we expected to see a decrease in MAP with lateral turning. Bein et al observed an increased heart rate in the left and right positions and decreased MAP on the right side 15 minutes after a manual turn, whereas in our study, clinically important changes had abated before then in all but 2 patients. Differences in recovery time may be related to different populations of patients, turning protocols, and number of measurements of heart rate and MAP.

Our study differed from that of Bein et al in 4 ways. First, the mean score on the Acute Physiology and Chronic Health Evaluation II was higher in our patients (29 vs 20). Second, only 46% of our patients were receiving cardiotropic medications whereas all of the patients in the study by Bein et al were. Third, patients were turned to mean angles of 50° on our study and 62° in the other study. Fourth, we measured hemodynamic response to lateral turning continuously, whereas Bein et al obtained 1 measurement after patients had been in the lateral position for 15 minutes. Perhaps, in our study, turn angles were insufficiently steep to reduce venous return and cardiac output. Patients were laterally rotated to an angle of 62° in those studies in which differences between left and right positions were found. In our study, marked increases in heart rate and MAP with manual turns were reproducible and transient, suggesting that the physical turning maneuver produced an autonomic nervous system response that resolved with time in the lateral position.

All patients in our study tolerated lateral turning. The patient whose data are shown in Figure 1 (P001) was the worst-case scenario in the study sample, with the greatest magnitude of response to turning. Clinicians are apprehensive about turning patients who have dramatic responses to turning. If turning were aborted on the basis of these grounds, patients with dramatic responses could conceivably be in the back position for days, putting them at risk for a host of pathological sequelae. One patient enrolled in our study could not start the study protocol because SBP in the back position decreased to less than that specified in a rotation “stopping rule.” Of note, patients with unstable hemodynamic status, defined for our study as SBP less than 90 mm Hg in the back position in patients receiving vasopressors, were not eligible to participate in the trial. Thus, our findings do not apply to patients receiving mechanical ventilation whose hemodynamic status is unstable.

Even though our patients were randomly selected by using a scientifically valid method for generalizability, the small number of patients in the sample limits generalizability to adult patients treated with mechanical ventilation in a medical-surgical intensive care unit, particularly for the MAP and pulse pressure findings. Our findings provide an uncommon characterization of nearly continuous hemodynamic response to lateral rotation with manual and automated turning. Other investigators with comparable study objectives and populations of patients had far fewer data points than we did: 36 data points for heart rate and MAP with a sample size of 12. The nearly continuous characterization of hemodynamic changes increases the validity of our findings. Furthermore, the visual ensemble averages validate the statistical findings. Ensemble averaging offers advantages for characterizing such time-dependent data as heart rate, MAP, and pulse pressure; it improves precision and provides a graphical footprint to visually enhance interpretation.

| Table 2 Summary of within-subject recovery time for heart rate, mean arterial pressure, and pulse pressure for the manual-turn group (n = 6) |
|-----------------|-----------------|-----------------|-----------------|
| Patient        | Recovery time, range (mean [SD]), min |
|                | Heart rate      | Mean arterial pressure | Pulse pressure  |
| P001           | 24° to ≥ 45° (35° [16]) | 17° to 37° (27° [14]) | 5° to 10° (8° [4]) |
| P002           | 9° to 32° (21° [16]) | 16° to ≥ 37 (27° [15]) | 19° to ≥ 43° (31° [17]) |
| P003           | ≥ 44° to ≥ 45° (45° [1]) | 9° to 19° (14° [7]) | 4° to ≥ 39° (22° [25]) |
| P004           | 9° to ≥ 45° (28° [26]) | Not applicable (no arterial catheter) | Not applicable (no arterial catheter) |
| P005           | ≤ 1 to 16° (8° [11]) | Not applicable (no arterial catheter) | Not applicable (no arterial catheter) |
| P006           | 34° to ≥ 38° (36° [3]) | Not applicable (no arterial catheter) | Not applicable (no arterial catheter) |

* Clinically significant: recovery time ≥ 5 minutes.
Figure 2  Manual-turn responses of heart rate (A, D), mean arterial pressure (B, E), and pulse pressure (C, F) in patient P001. A, B, and C show the time series for 4 individual turns from back to left position. D, E, and F show the corresponding ensemble averages for a complete turn cycle (back to left, left to back, back to right, and right to back). Vertical lines indicate the times of the turns.
Conclusions and Implications

Lateral turning every 2 hours is a standard of care to minimize complications associated with immobility. Previous research has indicated adverse, albeit transient, hemodynamic effects with lateral turning. Clinicians are therefore often reluctant to turn patients, fearing adverse effects in patients who are already physiologically compromised.

Our findings suggest that patients receiving mechanical ventilation in a medical-surgical intensive care unit may experience changes in heart rate, MAP, and pulse pressure when manually turned to 45° or more, but clinically important changes are transient and related to the turning maneuver. No differences between left and right lateral turning should be anticipated with turn angles of 50° or less. Clinically important hemodynamic changes subside within 15 minutes after the turn; modest changes may persist for up to 45 minutes. In our patients, the magnitude of change in heart rate, MAP, and pulse pressure was tolerated clinically, and patients remained in the lateral position for the 2-hour turn period. Automated lateral turning in a specialty bed designed to turn to an angle of 40° or more appears to have no adverse hemodynamic effects and may be a safer turning method for patients whose hemodynamic status is unstable. Further research with a larger sample size is indicated to validate our findings, and future research should be conducted in patients with hemodynamic compromise to determine their ability to tolerate manual and automated lateral rotation.

ACKNOWLEDGMENTS

We thank Audrius Brazdeikis, PhD, research associate professor, University of Houston, Houston, Texas, for assistance with programming data acquisition. A special thanks to Mara Baun, RN, DNSc, FAAN, who served as member of the first author’s dissertation committee.

FINANCIAL DISCLOSURES

This project was supported by the American Association of Critical-Care Nurses Mentorship Grant, American Association of Critical-Care Nurses Houston-Gulf Coast Chapter Research Grant, Society of Critical Care Medicine Norma J. Shoemaker Nursing Research Grant, and the Texas Medical Center Howell Nursing Research Grant.

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