31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Cardiovascular Impact of Manual and Automated Turns in ICU

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***Abstract*— Mechanically ventilated patients in the intensive care unit (ICU) are typically turned manually by nursing staff to reduce the risk of developing ventilator associated pneumonia and other problems in the lungs. However, turning can induce changes in the heart rate and blood pressure that can at times have a destabilizing effect. We report here on the early stage of a study that has been undertaken to measure the cardiovascular impact of manual turning, and compare it to changes induced when patients lie on automated beds that turn continuously. Heart rate and blood pressure data were analyzed over ensembles of turns with autoregressive models for comparing baseline level to the dynamic response. Manual turning stimulated a response in the heart rate that lasted for a median of 20 minutes and was of magnitude 5 to 13 bpm. The corresponding response in mean arterial pressure was 11 to 19 mm Hg, lasting for 8 to 21 minutes. There was no discernible response of either variable to automated turns.**

I. Introduction

Mechanical ventilation is a common intervention in the intensive care unit (ICU) aimed at providing vital oxygen to tissues. Sedation, paralysis, and mechanical ventilation itself impedes a patient's ability to mobilize and expel rapidly accumulating secretions thereby increasing the risk for developing ventilator associated pneumonia (VAP) and death. This risk is mitigated by the practice of turning patients from side-to-side periodically to mobilize stationary secretions. Nursing staff in the ICU are generally wary of a possible destabilizing influence of turning on cardiovascular variables, such as heart rate and blood pressure. Adverse cardiovascular responses to turning, although common, should return to baseline values (pre-turn values) in ≤ 5 minutes [1].

Recently, some ICUs have experimented with the introduction of automated beds that continuously rotate the plane of the bed around a lengthwise axis through the center of the bed. The expectation is that continuous turning will reduce the risk of developing VAP by increasing secretion mobilization [2]. However, cardiovascular response to continuous side-to-side movement has not been determined. Our ongoing randomized clinical trial (RCT) study design is aimed at measuring the cardiovascular response to manual and automated turning in ICU patients (ClinicalTrials.gov: NCT00542321). In this preliminary report we present the methods developed for analysis over an ensemble of turns of autocorrelated heart rate and blood pressure data, illustrated with a case study of two participants: one manually and one automatically turned.

It is found that manual turns induce increases in heart rate and blood pressure that last several minutes, regardless of the direction of the turn. There are four types of turns: patients can be turned from lying on their back to lying with 45 degree inclination to their left or to their right, and reverse turns from either side to lying on their back. Ensemble averages were computed for all turns within each turn category. For the automated turns, angles were measured continuously and an ensemble average was computed across all turns. The blood pressure measurements needed correction due to angle-dependent changes in the height of the transducer used to measure blood pressure. The heart rate and corrected blood pressure did not show a statistically significant response to the automated turns.

II. Methods

A. *Settings and Subjects*

Randomized selection and assignment to manual and automated turning groups is being used for enrollment of participants into the study. Potential participants are patients admitted to ICUs at The Methodist Hospital (TMH) and St. Luke's Episcopal Hospital (SLEH) in the Texas Medical Center. The Institutional Review Boards approved the study. The manual-turn patient was a 77 year-old Hispanic male, with a primary diagnosis of pneumonia with severe sepsis, body weight of 68 kg, and APACHE II (severity of illness measure) score of 25. The automated-turn patient was a 53 year-old Caucasian male, with a primary diagnosis of pneumonia, body weight of 157 kg, and APACHE II score of 22.

B. *Data Collection*

A data acquisition system for the TMH site was implemented in C# (Microsoft Visual Studio .NET 2003, Microsoft Inc. Redmond, WA) to collect heart rate and

Manuscript received April 23, 2009. This work was supported in part by The Texas Medical Center Howell Nursing Research Grant, the Society of Critical Care Medicine Norma J. Shoemaker Nursing Research Grant, the American Association of Critical-Care Nurses (AACN) Mentorship Grant, and the AACN Houston Gulf-Coast Chapter Research Grant.

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arterial blood pressure data via a serial port from the Philips CMS hospital monitoring system. The BedMaster software (Excel Medical Electronics, Inc, Jupiter, FL) was used for the SLEH site to collect physiological data from Solar 8000 monitors (GE/Marquette, Milwaukee, WI) every six seconds via the Unity Network (GE Medical Systems Information Technologies). The monitoring systems provided systolic and diastolic values of the blood pressure waveform and heart rate for a minimum of 24 hours on each subject. Mean arterial pressure (MAP) was calculated as a weighted sum of systolic (weight = 2/3) and diastolic (weight = 1/3) blood pressure values.

In the case of participants who were randomly assigned to the manual-turn group, times and directions of the turns were noted by the research nurse. Turns were approximately two hours apart. Turn times denote the beginning of the turns, but they were estimated and noted after the turn was over, which introduced an uncertainty of up to ±5 minutes in the turn times. Cushions were used to maintain a chest angle ≥ 45 degrees to the vertical.

The automated beds (Triadyne Proventa, Kinetic Concepts, Inc., San Antonio, TX) had air-filled mattresses and rotation was accomplished by alternately inflating and deflating sections of the mattress. The bed rotation cycle time was approximately 12 minutes, with variation of up to 90 seconds depending on patient weight. The built-in angle measurement had some deficiencies for the requirements of the study. At our request, the company outfitted the research beds with a second angle sensor for a real-time angle of turn readout from the research beds. The angle data were read into the VI Logger (National Instruments, Austin TX) using a 12-bit data acquisition module (NI USB-6008, National Instruments, Austin, TX) at a sampling rate of one second. The measured angles corresponded to the mattress frame angle at the head of the bed, which could be different from the chest angle of a person lying on the air-filled mattress. We conducted an experiment with four healthy subjects to estimate the empirical correction to the calibration curve that allowed us to estimate chest angles that were accurate within 5 degrees. The sensor data conversion (voltage to angle), calibration, angle correction, and time synchronization across the physiological and the angle of turn data were implemented in LabView software (National Instruments, Austin, TX).

C. *Statistical Signal Processing*

Heart rate and blood pressure data were extracted for each manual turn starting 15 minutes before the turn and extending 45 minutes past the turn time. Data were resampled into uniform 12-second bins. The larger sampling interval was chosen to reduce high autocorrelation in the original data. Extreme outliers that were beyond a 3-interquartile range spread from the first and third quartiles of the distribution were discarded to reduce impact on generalized least squares models that were used subsequently. Ensemble averages were computed of all turns that belonged to a turn category (back-to-left, left-to-back, back-to-right, and right-to-back). One back-to-left turn was excluded because it showed a physiological response to the turn that substantially preceded the noted time of turn. Statistical signal processing was scripted in S-Plus 8.0 (Insightful, Inc., Seattle, WA.)

Individual turns as well as ensemble averages were analyzed to determine the time required for each variable to return to baseline values. The baseline interval was defined to be the first 5 minutes of each turn, a time interval that ends approximately 10 minutes before the noted turning time. This choice ensures that the baseline interval ended before the turn, even after accounting for the uncertainty in the noted time of turn.

The time to return to baseline was estimated using generalized least squares models that took into account the autocorrelation structure of the variables [3]. Each model compared the 5-minute baseline to a 5-minute test interval. The first test interval began at the end of the baseline interval and starting points of subsequent test intervals were moved forward in 1-minute increments. Models were intercept-only models, i.e. the mean level was compared taking into account the autoregressive (AR) structure. Order of AR structure was decided by minimizing the Akaike information criterion for each additional parameter that was estimated [4]. Since the first order AR(1) structure was optimal in all but two instances, model order was fixed at one for uniform treatment. During the dynamic response phase, the intercept-only model is not expected to fit the data well. Statistically significant differences vanish when the variable approaches a quiescent state that has statistical properties similar to the baseline interval. It is valid to extend this approach from individual turns to the ensemble average since the mean of all processes with identical AR parameters is also an AR process.

Automated turn data were binned into 10-degree angle bins that were also distinguished by direction of movement so that a picture of the entire rotation cycle could be obtained. Thus, bins were numbered from 1 to 5 for rotation from 0 degrees (lying on back) to 50 degrees to the right, 6 to 10 on the way back from right to the center, 11 to 15 from 0 degrees to 50 degrees to the left, and 16 to 20 on the way

TABLE I
MEAN RESPONSE OF HEART RATE TO MANUAL TURNS

Turn	Duration of Response	Magnitude of Response
Back-to-Left	45+ min[a]	9 bpm
Left-to-Back	13 min	5 bpm
Back-to-Right	27 min	12 bpm
Right-to-Back	13 min	13 bpm

The magnitude of response is the maximum difference between the autocorrelation-adjusted mean of test intervals and the baseline. The duration of response is the time for return to baseline.

[a]No return to baseline within observation window.

back from left to the center. All available turns were accepted from the longest time interval that had no more than 1 minute of missing data, and in which there were no sudden changes of angle. Sudden changes of angle can occur at times when the bed is stopped and the research staff resets the bed to the center.

The automated turn data were analyzed using longitudinal mixed effects models that allowed random intercept (change of mean level) for each turn in each angular bin, and provided an estimate of the fixed effect intercept (overall mean level) after accounting for autocorrelation structure within each turn. The 95% confidence intervals of the mean for each bin provide an estimate of the variability. If there is no overlap between the confidence intervals of two bins, it may be concluded that there is a statistically significant difference between the bins.

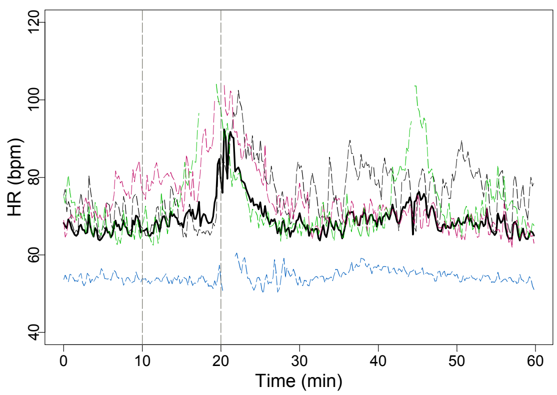

Fig. 1. Heart rate response to manual turns from right-to-back. Colored dashed curves represent individual turns and the black solid curve is the ensemble average. Dashed vertical lines show band centered at 15 min in which turns occurred.

III. RESULTS

Manual turns were observed to induce a response in heart rate and blood pressure. The heart rate response lasted for a median of 20 minutes before returning to baseline level. The magnitude of the response varied between 5 and 13 bpm (see Table I and Fig. 1). Autocorrelation AR(1) parameters for baseline heart rate ranged from 0.55 to 0.67, with median value 0.62. The blood pressure response lasted between 8 and 21 minutes before returning to baseline level. The magnitude of the response varied between 11 and 19 mm Hg (see Table II and Fig. 2). Autocorrelation AR(1) parameters for baseline MAP ranged from 0.48 to 0.99, with median value 0.78. In the turns to the side, i.e. away from the center, the duration of response for heart rate was longer and the magnitude of response for MAP was slightly higher.

TABLE II
MEAN RESPONSE OF MAP TO MANUAL TURNS

Turn	Duration of Response	Magnitude of Response
Back-to-Left	12 min	19 mm Hg
Left-to-Back	21 min	11 mm Hg
Back-to-Right	14 min	16 mm Hg
Right-to-Back	8 min	16 mm Hg

The magnitude of response is the maximum difference between the autocorrelation-adjusted mean of test intervals and the baseline. The duration of response is the time for return to baseline.

In automated continuous turns there is no evidence of a response of heart rate (see Fig. 3) and blood pressure (see Fig. 4) to turning. The blood pressure had an apparent angle-dependence, which disappeared upon correction due to change in the height of the measurement transducer and/or

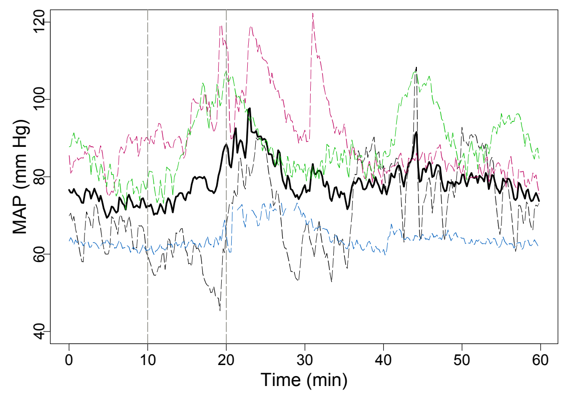

Fig. 2. Mean arterial blood pressure response to manual turns from right-to-back. Colored dashed curves represent individual turns and the black solid curve is the ensemble average. Dashed vertical lines show band centered at 15 min in which turns occurred.

tubing. The correction was computed on the basis of a model $MAP = MAP_0 + a(1-\cos(\theta/5)) - b\sin(\theta)$, where MAP_0 is a constant level, θ is the angle of rotation, a is the precession arm length, and b is the asymmetry arm of the measurement point from the bed's axis of rotation. Precession angle was assumed to be linearly related to the rotation angle, and a regression model was used to estimate a and b. The model (see Fig. 4) takes into account the change in height of a point on the surface of the bed that is away from the axis of rotation, as well as movement of the center of the bed due to a precession effect from the air-filling mechanism. Slippage of the patient on the bed surface can also enhance the precession effect. The maximum displacement estimate resulting from the regression model was approximately 10 cm.

IV. DISCUSSION

Cardiovascular response to manual turning of a patient in the ICU was measured in the variables of heart rate and blood pressure. The magnitude of response in both variables would be considered clinically important, and the responses lasted for a median 13 minutes after the turn. In the ensemble averages, the largest heart rate response was 13 bpm and the largest MAP response was 19 mm Hg. The response appears to be related to the process of turning

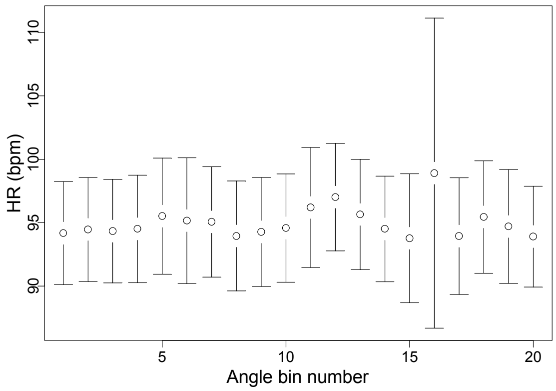

Fig. 3. Heart rate response to one cycle of ensemble average of 56 automated turns. Each bin represents 10 degree increments. The first 5 bins represent rotation from center to right, bins 6-10 from right to center, bins 11-15 from center to left, and bins 16-20 from left to center. Error bars represent 95% confidence intervals.

rather than to the direction of the turn. However, this deserves further study since a longer heart rate response and a slightly higher MAP response was provoked in turns to the side, i.e. away from center. Automated continuous turning of a patient in the ICU did not provoke a significant response

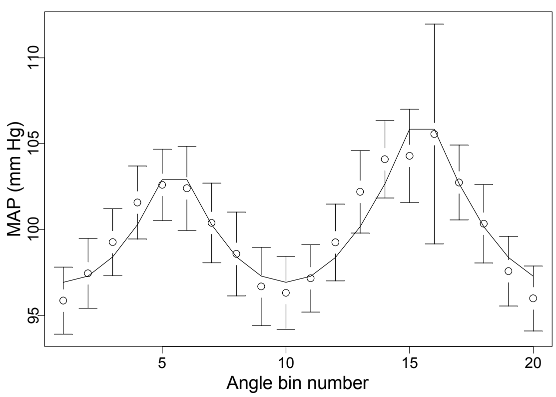

Fig. 4. Mean arterial blood pressure response to one cycle of ensemble average of 56 automated turns. Each bin represents 10 degree increments. The first 5 bins represent rotation from center to right, bins 6-10 from right to center, bins 11-15 from center to left, and bins 16-20 from left to center. The solid curve is the estimated variation due to height changes in measurement of blood pressure. Error bars represent 95% confidence intervals.

in the cardiovascular variables, which suggests that there may be an advantage offered by this method of turning that could reduce fears of destabilizing the ICU patient. It would be necessary, however, to study whether the faster period of automated turning might induce a constant (angle-independent) response that may result in a higher heart rate and blood pressure. Another limitation of the results presented here is that it represents only the early-stage results of the study from two ICU patients. Addition of more subjects will result in uncovering patterns of responses and allow us to investigate more rigorously the question of whether the direction of turns is related to the duration and magnitude of the cardiovascular response.

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