






RESEARCH ARTICLE

Significance of intra-operative blood pressure data resolution: A retrospective, observational study [version 1; peer review: 2 approved]

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Abstract

Background: With evolving techniques for analysis of blood pressure (BP) variability, the importance of sampling resolution for intra-operative BP still remains to be examined. This study aims at comparing BP data with beat-by-beat vs. 15 second resolution.

Methods: This is a retrospective analysis of intra-arterial BP data obtained from cardiac surgical patients from the intra-operative period. Data was collected from two sources for each patient, one with beat-by-beat frequency, other at a frequency of once every 15 seconds. The fraction of time and area under the curve beyond systolic BP thresholds of 95 – 135 mmHg were calculated using data from both sources, for each patient. These were compared using Wilcoxon ranked sum test for paired samples using R-statistics version 3.4.3.

Results: There was a statistically significant difference ($P < 0.001$) between the parameters from the two sources. This was especially true for parameters below and outside the thresholds. Only time fraction showed significant difference above the 135 mmHg threshold.

Conclusion: Our preliminary analysis shows a definitive difference between BP descriptors, depending on sampling resolution. But the impact of this difference on the outcome predicting models of the parameters stands to be ascertained. Future larger studies, powered to examine the impact of sampling resolution on outcome predictive ability of BP descriptors, with special emphasis on dynamic markers of complexity are warranted.

Open Peer Review

Reviewer Status  

Invited Reviewers

1

2

version 1

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report



report

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Any reports and responses or comments on the article can be found at the end of the article.

Keywords

Blood pressure, Beat by beat sampling, Cardiac surgery, Cardiopulmonary bypass

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Competing interests: No competing interests were disclosed.

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Introduction

Intra-operative blood pressure (BP) analysis has gained popularity not only because it forms a target for intervention and optimization, but also because of its predictive ability for major post-operative adverse events¹. Technology has contributed to the improved accuracy of invasive real-time BP monitoring, with high temporal resolution. But we do not yet know how much temporal resolution is an adequate resolution, for various BP analyses. This observational study was designed to address the above-said issue.

Many analytical techniques have been explored to decipher the information provided by the BP waveform. The journey began from absolute BP cut-offs to population thresholds, percentage changes from baseline^{1,2} to static^{3,4} and dynamic properties⁵ of the BP waveform. For this study, we computed the duration and area under the curve (AUC) beyond a certain BP threshold, as described by Aronson *et al.*³ They used invasive systolic BP (SBP) data, sampled every 30 seconds. The threshold used for final analysis was 95 and 135 mmHg of SBP. BP excursions beyond these thresholds were analysed in terms of the number of excursions and duration and magnitude of excursions, which were used to calculate the AUC above and below the thresholds. They found that the duration of excursion showed the most significant association with 30-day mortality. For every minute of excursion outside the threshold, the odds ratio for an increase in mortality was shown to be 1.03, using a multiple logistic regression model.

Beat-by-beat (BBB) sampling provides a voluminous quantity of data to store and analyse. But we do not know if this would significantly improve the outputs of various analytical methods. We sought to clarify the importance of the sampling resolution in BP variability analyses. We hypothesized that SBP parameters (time and AUC outside the range of 95–135 mmHg) computed from BBB BP data would be significantly different from the same descriptors derived from low-resolution BP data, sampled every 15 seconds.

Methods

Study design and setting

This is a retrospective, observational, single center, exploratory analysis conducted at Beth Israel Deaconess Medical Center, after the approval of the Institutional Review Board (approval number: 2008P000478). BP data was collected from 200 patients who underwent cardiac surgery between January 2008 and June 2014, from an ongoing NIH funded study (ROIGM098406), after verbal informed consent.

This manuscript adheres to the STROBE statement guidelines.

Participants

All patients over 18 years of age, undergoing elective cardiac surgery under cardiopulmonary bypass were considered eligible for BP data collection. This cohort was chosen because of the highly protocolized nature and the relatively tighter peri-operative BP control employed in the setting of a cardiac surgery. Baseline parameters such as age, gender, comorbidities, medications, nature of surgery, and risk scores were also collected.

All the patients had a radial arterial catheter inserted during the pre-operative period. BBB waveforms were securely exported from OR Philips monitors (Philips Medical, Andover, MA). BP data sampled every 15 seconds was also collected for all the patients via the institution's Anesthesia Information Management System (AIMS) (CompuRecord, Philips Healthcare, Andover, MA, USA). The BP data was pre-processed to remove artefacts. After excluding BP data of insufficient quality and length, 193 datasets were included in the final analysis.

Data analysis

We calculated the duration and AUC (magnitude times duration of excursions) of SBP outside 95–135 mmHg range. This included duration and AUC above, below and outside the SBP range. These parameters were calculated both from BBB and AIMS data for each patient. To standardize for the differences in the duration of data acquisition between BBB and AIMS, time fraction outside the thresholds was used for final analysis, rather than the absolute duration.

Statistical testing was performed using R version 3.4.3. Data are presented as median (interquartile range) or n (%) depending upon the variable. Shapiro Wilk Test was used to test for normality. Wilcoxon Rank-Sum test for paired samples was used to compare BP descriptors between BBB and AIMS data.

Results

The baseline characteristics of the patient cohort are described in [Table 1](#). We were able to find a statistically significant difference in AUC and time fraction between BBB and AIMS data, below (< 95 mmHg) and outside the range ($P < 0.001$; [Table 2](#)). A similar significant difference was also found with the fraction of time above the threshold ($P = 0.03$; [Table 2](#)). The AUC above the range (>135 mmHg) was similar between BBB and AIMS data. In general, both the descriptors had lower values when calculated from BBB data, compared to AIMS data.

Dataset 1. Variables collected throughout this study for the 193 participants

<http://dx.doi.org/10.5256/f1000research.13810.d196106>

Table 1. Baseline characteristics of the patient cohort.

Variables*	Total N=193
Age (Yrs)	68 (59, 76)
Gender (Male)	125 (64.8)
Surgery type	
CABG	73 (37.8)
Valve	40 (20.7)
CABG+Valve	33 (17.1)
Other	47 (24.4)
Cross clamp time (mins)	72 (55, 94) n=181
Comorbidities	
Hypertension	161 (83.4)
CHF	66 (34.2)
CVD	30 (15.5)
Dyslipidemia	141 (73.1)
Previous MI	52 (27.1)
Diabetes	60 (31.1)
Chronic Lung Disease	29 (15.1)
Smoking	21 (11)
Pre-operative medications	
Beta Blockers	147 (76.2)
ACEI / ARB	80 (41.5)
Risk scores	
STS risk algorithm	0.01 (0.006, 0.04) n=131
STS renal failure	0.03 (0.01, 0.07) n=130
STS morbidity and mortality	0.1 (0.08, 0.2) n=131

* Variables are presented as N (%), mean ± SD, or median (IQR) based on the type and distribution.

Table 2. Comparison of BP descriptors from BBB vs. AIMS. BP, blood pressure; BBB, beat-by-beat; AIMS, Anesthesia Information Management System; AUC, area under the curve.

Variable	BBB	AIMS	P-value
AUC above range**	178.37 (60.66, 409.80)	204.00 (57.25, 434.25)	0.66
AUC below range	370.19 (223.27, 556.99)	754.25 (494.00, 1021.25)	<0.001*
AUC outside range	625.99 (414.49, 923.70)	1082.25 (763, 1393.75)	<0.001*
Fraction of time above range	0.08 (0.03, 0.17)	0.08 (0.03, 0.15)	0.03*
Fraction of time below range	0.23 (0.16, 0.31)	0.25 (0.19, 0.34)	<0.001*
Fraction of time outside the range	0.35 (0.27, 0.44)	0.36 (0.30, 0.44)	0.03*

* Statistical significance P < 0.05.

** In mmHg per minute.

All values are median (IQR).

Discussion

The time fraction and AUC of SBP excursions were significantly lower with the BBB data when compared to the AIMS data. This could be explained by the fact that the data points in the AIMS data represent values averaged over 15 seconds. The 15 seconds duration between subsequent data points in AIMS data would accommodate approximately 15 or more BBB data points depending on the heart rate and this extrapolation could account for the relatively larger time fraction and AUC obtained from AIMS data. AUC below and outside the range showed significant difference ($P < 0.001$) between the two sources. Fraction of time above, below and outside the range showed significant difference (Table 2).

The descriptors used in this study are static parameters and do not take into account the temporal structure of the BP waveform. Hence intuitively, the impact of sampling frequency should be relatively less. But when we consider measures such as the multi-scale entropy^{5,6}, non-linearity⁷, which measure the temporal dynamics and complexity of the BP waveform, BBB data would prove to be significantly more accurate compared to lower resolution data. This could be a topic for future studies.

Our study is limited by the sample size included in the analysis. For the same reason, it was underpowered to analyse outcome correlation of the parameters studied. Also, only two BP

parameters were used in the study among a number of other parameters described in the literature.

Conclusions

We were able to show that the BP parameters differed significantly depending on the frequency of source data acquisition. Future directions include studies that are adequately powered to test the impact of sampling resolution on the ability of the parameters to predict outcomes, as well as analyzing the significance of data resolution in computing other BP parameters of variability and complexity.

Data availability

Dataset 1: Variables collected throughout this study for the 193 participants. [10.5256/f1000research.13810.d196106](https://doi.org/10.5256/f1000research.13810.d196106)⁸

Competing interests

No competing interests were disclosed.

Grant information

Balachundhar Subramaniam, MD, MPH, is supported by the National Institutes of Health, Research Project Grant GM 098406.

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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Version 1

Reviewer Report 15 June 2018

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Goverdhan Dutt Puri

Department of Anaesthesia and Intensive Care, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, Punjab and Haryana, India

I have only following suggestions/questions

1. Though the absolute difference in fraction of time for the two methods of data collection is very small (Table2) but the difference in AUC beyond specified thresholds is almost double. Is it due to difference in the valid time period of analysis by two different methods i.e. BBB and AIMS? In that case it would be better that the time period analyzed in each patient by two different methods be also depicted - the explanation given by authors is not satisfactory. Looking at the time period of analysis by two methods may clarify it.
2. Is the Philips monitor sending the data for AIMS every 15 second or every 5 seconds? Is the data averaged after collection at server or before being sent from peripheral monitor to central server?
3. How is area under curve calculated for AIMS data? If the peak of wave was SBP, what was time dimension – is it the total systolic time or total epoch time of 15 sec? As no waveform was available in this case. Or was it the SBP above the threshold multiplied by the time till next SBP value comes within the threshold?
4. Why was MAP not chosen?

Otherwise it's a well written manuscript with great future implications.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: I am involved with closed loop blood pressure control system development

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response () 19 Jun 2018

Senthil Packiasabapathy, Harvard Medical School, Boston, USA

Thank you for your approval and kind comments! Please find the response to your queries below.

1. Though the absolute difference in the fraction of time for the two methods of data collection is very small (Table2) but the difference in AUC beyond specified thresholds is almost double. Is it due to the difference in the valid time period of analysis by two different methods i.e. BBB and AIMS? In that case, it would be better than the time period analyzed in each patient by two different methods be also depicted - the explanation given by authors is not satisfactory. Looking at the time period of analysis by two methods may clarify it.

Thank you for your question. Yes. The area under the curve values is almost double due to the difference in valid time period analysis. The various values of the fraction of time as a part of time period analysis is given under the data sheet in excel in the article.

2. Is the Philips monitor sending the data for AIMS every 15 second or every 5 seconds? Is the data averaged after collection at server or before being sent from peripheral monitor to central server?

Thank you. The OR Philips monitor secured the beat by beat data while the Anesthesia Information Management System (AIMS) collected the blood pressure data every 15 seconds.

3. How is area under curve calculated for AIMS data? If the peak of wave was SBP, what was time dimension – is it the total systolic time or total epoch time of 15 sec? As no waveform was available in this case. Or was it the SBP above the threshold multiplied by the time till next SBP value comes within the threshold?

Thank you. Area under curve (AUC) was analyzed as the summation of the integrated SBP-time curve excursions, capturing the product of magnitude (mm Hg) and duration (min) of BP outside the predefined SBP ranges. So it was total epoch time of 15 seconds.

4. Why was MAP not chosen?

Thank you. We chose intraoperative systolic blood pressure over mean arterial pressure following the methodology mentioned in the article by Aronson et al.¹

Reference:

"Aronson S, Stafford-Smith M, Phillips-Bute B, et al.: Intraoperative systolic blood pressure variability predicts 30-day mortality in aortocoronary bypass surgery patients. *Anesthesiology*. 2010; 113(2): 305–12."

Competing Interests: No competing interests to be declared

Reviewer Report 15 March 2018

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This well written manuscript compared blood pressure data collected using two sampling resolutions: beat-by-beat contours vs. numeric data captured q15 seconds. This study represents an important first step to validating and comparing hemodynamic data obtained using different sampling methods and proposes the concept of time fractions as a standardizing method to account for case duration. The authors provided a thoughtful discussion of main findings. As the authors suggested, future studies of the association between different sampling methods and outcomes would be very interesting and a welcomed addition to the literature

We have only minor suggestions:

1. Can the authors briefly explain what constituted artefacts and how artefacts were removed from BBB tracings and from the AIM data? Also did these algorithms produce consistent removal of artefacts in both BP recording modalities?
2. The authors are to be commended for their use of time fraction. Can the authors clarify the method of calculation for time fraction (i.e., was case duration used as the denominator)?
3. Looks like although the median AUC values were very different between the BBB and AIMS groups, their corresponding time fractions were not very different (despite statistical significance).

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cardiac Anesthesiology, Hemodynamic monitoring, Epidemiology

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response () 21 Mar 2018

Senthil Packiasabapathy, Harvard Medical School, Boston, USA

Thank you reviewers, for your approval and kind comments!

1. Can the authors briefly explain what constituted artefacts and how artefacts were removed from BBB tracings and from the AIM data? Also did these algorithms produce consistent removal of artefacts in both BP recording modalities?

An automated algorithm was used to eliminate artifacts. It excluded SBP values < 50 mm Hg and > 250 mm Hg; DBP values < 20 mm Hg and > 150 mm Hg; $DBP \geq SBP$, and $SBP - DBP < 10$ mm Hg. Yes this was used for both BP sources.

2. The authors are to be commended for their use of time fraction. Can the authors clarify the method of calculation for time fraction (i.e., was case duration used as the denominator)?

Thank you, Time fraction was used because the total duration of BP data acquisition could be different for BBB and AIMS. The total duration for which BP data was acquired was used as the denominator.

3. Looks like although the median AUC values were very different between the BBB and AIMS groups, their corresponding time fractions were not very different (despite statistical significance).

Yes, agreed. AUC takes into account both the magnitude and duration of the BP excursions. As we see there is not a lot of difference in the time fraction (despite statistical significance), it is possible that the difference in the magnitude between BBB and AIMS has contributed to the differences in AUC.

Competing Interests: No competing interests to be declared.

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