

# Contactless Monitoring of Vital Parameters by Ballistocardiography Compared with Bedside Monitors: A Prospective Observational Study

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## ABSTRACT

**Introduction:** Ballistocardiography (BCG) is a technique of contactless monitoring of the body's vital parameters. During ventricular systole, aortic blood flow produces minuscule body displacements which can be picked up by piezoelectric sensors placed under the patient's mattress. The BCG monitor connected to the sensors analyses these body displacements and generates basic vital parameters, which are displayed on a mobile device or computer. BCG devices may demonstrate improved compliance due to its unobtrusive nature, as well as affordability compared to standard bedside monitors, although their reliability remains unclear.

**Aim:** To evaluate the accuracy of patients' vital parameters as measured by the BCG device (Dozee), by comparison with simultaneous readings on a reference device, the Philips IntelliVue MP20 bedside monitor.

**Materials and Methods:** This two-month prospective, observational study was conducted at the Intensive Care Unit (ICU) of Manipal Hospital, Yeshwantpur, Bengaluru, Karnataka, India from May 2023 to June 2023. All patients admitted to the ICU were assessed for the study, excluding those who were haemodynamically unstable or agitated, as well as those receiving haemodialysis, resulting in 121 patients who met the inclusion criteria. Routine vital parameters were obtained from each device, including Heart Rate (HR), Respiratory Rate (RR), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP),

Mean Arterial Pressure (MAP), Peripheral Oxygen Saturation (SpO<sub>2</sub>) and Temperature (Temp). Mean values from the Dozee device were similar to that of the bedside monitor using One Way Analysis of Variance (ANOVA) using F-test and a p-value < 0.05 was taken as significant. Patients' vitals were recorded at four-hour intervals during their stay in ICU.

**Results:** A total of 121 patients were included with a mean age of 62.6 ± 16.6 years. The readings of each parameter were obtained at four-hour intervals. About 900 - 1000 readings were obtained. There was a good agreement between the values measured by the BCG device and the bedside monitor, with a p-value of < 0.001 across all parameters: HR (mean 86.9 vs 82.9 beats/min), RR (20.8 vs 19.6 cycles/min), SBP (124.8 vs 122.8 mmHg), DBP (68.0 vs 67.7 mmHg), MAP (87.0 vs 85.3 mmHg), SpO<sub>2</sub> (96.2 vs 95.1 %) and Temp (97.5 vs 96.9 ° F). However, reliability of the data varied across the parameters, with the most accuracy noted only in HR and BP readings. The BCG device also failed to give readings in about 44 (4.4%) of 1000 readings obtained on the bedside monitor.

**Conclusion:** BCG devices can substitute for regular bedside monitors, although it is reliable only for measuring three vital parameters, HR, BP and RR. Although the contactless technology allows for better patient compliance, the present study suggests that it is safe for use only in bedbound patients who are relatively stable, or in conditions where bedside monitors or nursing care are unfeasible or unavailable.

**Keywords:** Artificial intelligence algorithms, Commercial health monitoring systems, Home medical monitor, Piezoelectric sensor, Polyvinylidene fluoride sensor, Remote patient monitoring

## INTRODUCTION

The BCG is a graphic recording of minute body movements resulting from forces generated by cardiac contraction and ejection of blood [1]. These movements are picked up by a sensor, translated into an electrical potential by an analogue-digital converter, amplified, filtered and then recorded as a waveform [2]. The waveform is analysed by proprietary algorithms to yield vital parameters such as HR, RR, SBP, DBP, MAP, SpO<sub>2</sub> and Temp.

The concept of blood circulation producing body displacements and their measurement was proposed by Gordon as early as 1877. He demonstrated that when a subject lay still on a weighing scale, the needle would vibrate synchronously to the subject's heartbeat [2,3]. In 1939, Starr and colleagues coined the term BCG to describe the use of this technology to assess parameters of cardiovascular dynamics such as stroke volume. The earlier BCG devices such as a table with a mobile top surface were bulky and signal analysis was complicated and impeded by artefacts. With

the advent of echocardiography, Electrocardiography (ECG) and doppler ultrasound in the 1950s, the BCG technology was largely abandoned [3].

However, with the advances in Bio-Medical Electromechanical Systems (BioMEMS), computer learning and sensors becoming more compact, the 21<sup>st</sup> century has seen a reawakening of interest in BCG. Newer portable and wireless BCG devices have been developed which can be placed on or under a mattress, on a wheelchair, or on the skin as a wearable device, allowing for remote health monitoring without the need for trained personnel [4,5].

The physiology behind BCG is a derivative of Newton's Third Law of motion, in that any sustained movement of mass within a body will result in a recoil motion of the body itself in the opposite direction [4]. During ventricular systole, ejection of blood into the ascending aorta produces a recoil of the body in the opposite cephalo-caudal direction. Next, when blood enters the descending aorta, there is a recoil of the body in the caudo-cephalic direction. The magnitude of

this recoil movement is proportional to the volume of blood ejected from the heart per beat [3,6]. These imperceptible body movements are sensed by displacement or force transducers attached to the subject's body or cot or chair. These are recorded as a waveform and interpreted using algorithms to derive valuable cardiovascular data such as HR, BP and ejection fraction [5,7].

The number of home medical monitors is growing exponentially including impedance cardiograms, electrocardiograms, nasal airflow, respiratory plethysmograms and pulse oximetry [8]. However, these are obtrusive as they require the patient to wear sensor pads consistently, such as ECG electrodes and BP cuffs. In comparison, BCG sensors are not required to be placed directly on the body [9]. Most studies on BCG have analysed the sensors and algorithms behind this technology, but none have validated the reliability of any BCG device available on the market by comparing with standard bedside monitors. The present study aimed to assess the reliability of a commercially available BCG device, the Dozee contactless monitor, in comparison with standard healthcare monitors. The null hypothesis proposed that there is no difference in readings between the two devices, while the alternate hypothesis proposed there is a significant difference.

## MATERIALS AND METHODS

This was a prospective, observational study conducted at the tertiary care ICU of Manipal Hospital, Yeshwantpur, Bengaluru, Karnataka, India, over a two-month period from May 2023 to June 2023. The study aimed to validate the accuracy of patients' vital parameters as measured by the Dozee BCG device by comparison with simultaneous readings on a reference device, the Philips IntelliVue MP20 bedside monitor. The study protocol was reviewed and approved by the Institutional Ethics Committee Columbia Asia Hospitals (now called Manipal Hospital Yeshwantpur), Brigade Gateway, Bangalore 560055 issued approval DCG (I) Reg No: ECR/105/Inst/KA/2013/RR19.

**Sample size:** In a similar study comparing a contactless monitoring system Alice NightOne with manual measurements of RR and HR, RR monitoring was linearly correlated with Alice NightOne and manual counts, presenting coefficients of determination of 0.88 and 0.90, respectively [10]. Contactless HR monitoring presented a coefficient of determination of 0.91. In the present study, expecting to get similar result with 80% power, 95% confidence level and considering the minimum co-efficient of  $r=0.815$ , the minimum sample size required was 145 subjects. But due to logistic reasons only 121 patients were obtained.

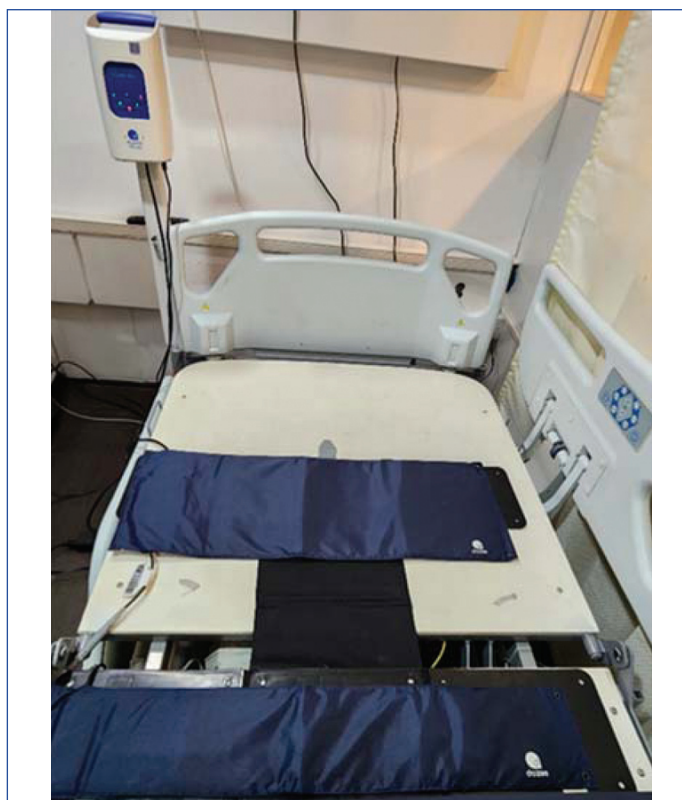
**Inclusion and Exclusion criteria:** All adult patients admitted to the ICU during the study period were enrolled in the study. Patients who were haemodynamically unstable, on haemodialysis or agitated were excluded from the study.

### Study Procedure

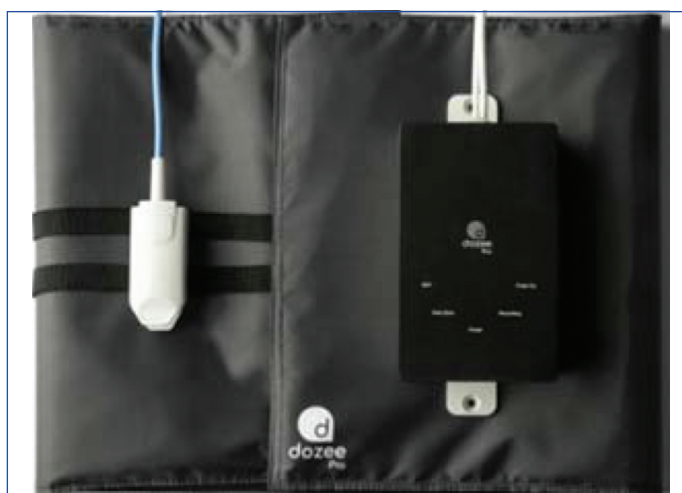
Routine parameters were compared, including HR, RR, SBP, DBP, MAP, SpO<sub>2</sub> and Temp. The Dozee device consists of a thin sensor strip 12 cm wide and 68 cm long which is kept below the patients' mattresses at the chest level, and a finger pulse oximeter probe [Table/Fig-1]. The sensor strip is connected by a cable to a data pod, a small 6.5x5 cm oval device kept at the bedside [Table/Fig-2]. The data pod transmits data wirelessly to a central monitor, which is then analysed. Vital parameters were noted simultaneously on both devices at four-hourly intervals, using a central monitor in the nursing station showing the bedside monitor readings, and a laptop showing readings from the BCG device.

**Outcome measures:** The outcome studied was the range of deviation of values measured by the Dozee BCG device from the benchmark readings of the Philips M20 bedside monitor.

With the exception of stroke patients, most of the subjects were freely mobile, but confined to bed while BCG readings were obtained.



[Table/Fig-1]: The Dozee device sensor strip and finger probe with data pod.



[Table/Fig-2]: The Dozee sensor strips place on cot and connected to data pod.

## STATISTICAL ANALYSIS

Data was analysed using Statistical Package for the Social Sciences for Windows, Version 16.0. Chicago, USA, SPSS Inc. Data were compared using Intraclass Correlation Coefficient (ICC) with 95% Confidence Interval (95% CI). ANOVA using F-test was used to compare variance between the means of the two groups,  $p < 0.05$  was taken as significant. Bland-Altman plots were obtained to analyse the degree of agreement between the Dozee BCG and Philips monitor readings, and to look for systemic bias.

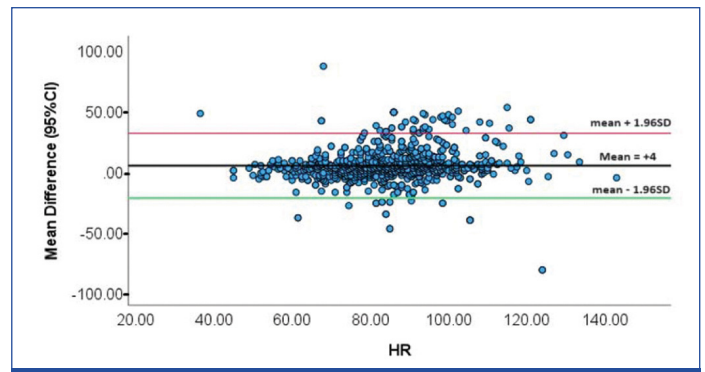
## RESULTS

A total of 121 patients were included in the study over the period of two months, out of whom 71 (59%) were male [Table/Fig-3]. The mean age was  $62.6 \pm 16.6$  years. Of the 121 cases, 28 were cardiology patients, 23 surgical, 20 each of sepsis and oncology, eight neurology, six neurosurgery, five respiratory, three each of orthopaedics, nephrology and gynaecology, and two gastroenterology.

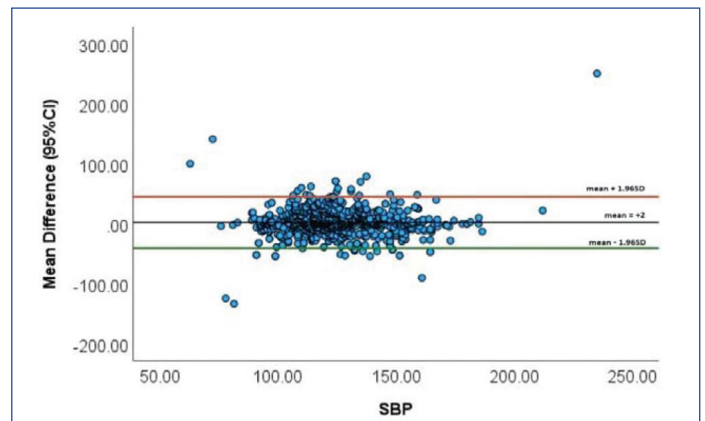
Based on the 95% CI of the ICC estimate, reliability of the data was excellent for DBP, good for HR, moderate for SBP, RR and SpO<sub>2</sub>, and poor for Temp [11]. The mean values recorded on the bedside

Demographics	n (%)
Age (Mean±SD)	62.6±16.6 years
<b>Gender</b>	
Male	71 (59%)
Female	50 (41%)
Body Mass Index (BMI) (Mean±SD)	25.72 (4.76)
APACHE II score (Mean±SD)	13.6 (7.23)
<b>Distribution of cases</b>	
Ischaemic heart disease	28 (23%)
Postoperative	23 (19%)
Sepsis	20 (17%)
Oncology	20 (17%)
Cerebrovascular accident	8 (6%)
Neurosurgery	6 (5%)
Chronic obstructive pulmonary disease	5 (4%)
Acute kidney injury	3 (2.5%)
Post-orthopedic surgery	3 (2.5%)
Post-emergency Caesarean section	3 (2.5%)
Chronic liver disease	2 (1.5%)

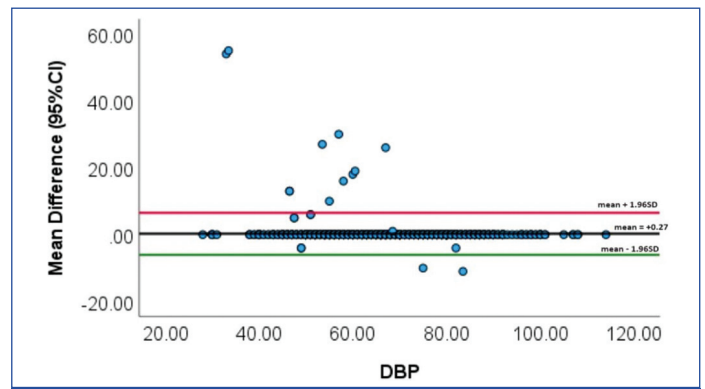
**[Table/Fig-3]:** Demographics, Acute Physiology and Chronic Health Evaluation (APACHE) II score and admission category of study patients (N=121). HR: Heart rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; RR: Respiratory rate; \*Data from Dozee monitor and bedside monitor compared using Intraclass Correlation Coefficient (ICC) with 95% Confidence Interval (95% CI). ANOVA using F-test was used to compare variance between the means of the two groups. p<0.05 was taken as significant



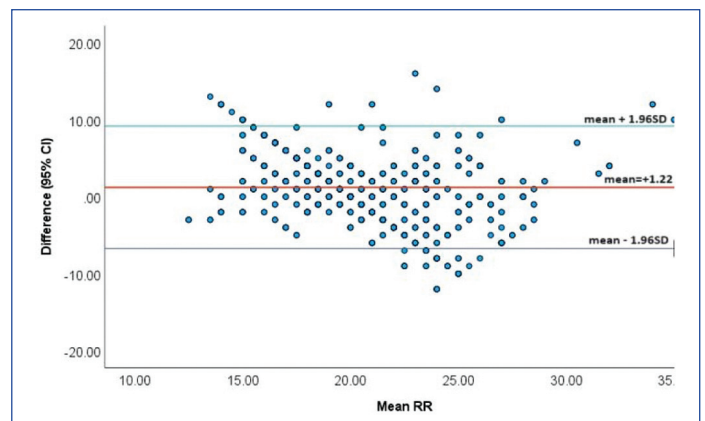
**[Table/Fig-5]:** Bland-Altman plot of Heart Rate (HR).



**[Table/Fig-6]:** Bland-Altman plot of Systolic Blood Pressure (SBP).



**[Table/Fig-7]:** Bland-Altman plot of Diastolic Blood Pressure (DBP).



**[Table/Fig-8]:** Bland-Altman plot of Respiratory Rate (RR).

monitor vs. the Dozee monitor were HR 86.9 vs. 82.9 beats/min, SBP 124 vs 122 mmHg, DBP 68 vs 67.7 mmHg, MAP 87.0 vs 85.3 mmHg, RR 20.8 vs 19.6 cycles/min, SpO<sub>2</sub> 96.2 vs 95.1 % and Temp 97.5 vs 96.9 °F.

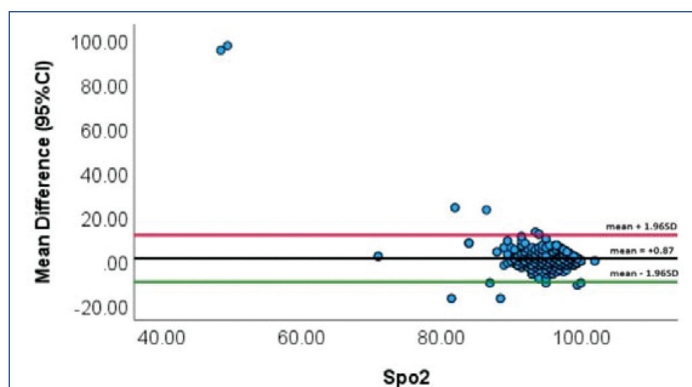
The total number of readings varied depending on the parameters measured - 982 readings were obtained for SBP, DBP, MAP, RR and SpO<sub>2</sub>, 907 readings of Temp and 1003 readings of HR [Table/Fig-4]. There was significant agreement between the Philips M20 and Dozee BCG method in measuring HR, SBP, DBP, MAP and RR (ICC=0.76, 0.67, 0.99, 0.74, 0.61, respectively), but poor agreement between SpO<sub>2</sub> and Temp (ICC 0.57 and 0.49, respectively) (p<0.001).

Parameters	Philips M20 (Mean±SD)	Dozee BCG (Mean±SD)	Intra-class Correlation (95%CI)	p-value	F-test
HR (n=1003)	86.9±16.1 beats/min	82.9±14.9	0.76 (0.73 - 0.79)	<0.001	4.171
SBP (n=982)	124.8±22.1 mmHg	122.8±21.7 mmHg	0.67 (0.62 - 0.71)	<0.001	2.995
DBP (n=982)	68.0±13.9 mmHg	67.7±14.3 mmHg	0.99 (0.98 - 0.99)	<0.001	7.386
MAP (n=982)	87.0±14.3 mmHg	85.3±14.4 mmHg	0.74 (0.71 - 0.77)	<0.001	3.898
RR (n=982)	20.8±3.1 cycles/min	19.6±4.4 cycles/min	0.609 (0.56 - 0.65)	<0.001	2.651
SpO <sub>2</sub> (n=982)	96.2±3.3%	95.1±4.7%	0.57 (0.51 - 0.62)	<0.001	3.437
Temperature (n=907)	97.5±1.3 °F	96.9±1.7 °F	0.49 (0.42 - 0.55)	<0.001	1.957

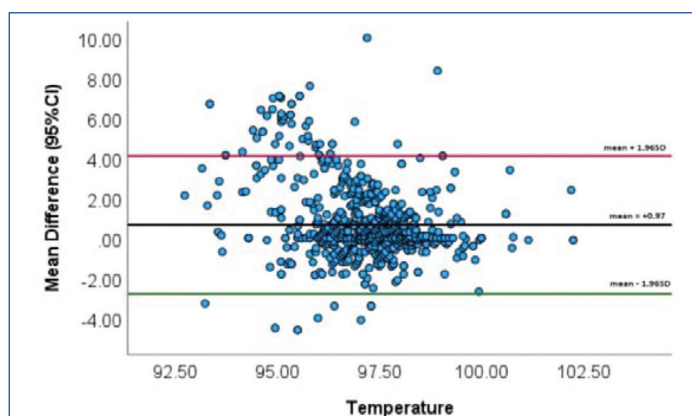
**[Table/Fig-4]:** Comparison between Philips monitor and Dozee measurements. HR: Heart rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; MAP: Mean arterial pressure; RR: Respiratory rate

In addition, the BCG device and bedside monitor readings were compared using the Bland-Altman method for repeated measurements [Table/Fig-5-10]. The figures show the mean of the readings obtained by two devices on the X axis and the difference between the two readings on the Y axis. The mean of the differences is shown as the middle horizontal line. The upper and lower Limits Of Agreement (LOA) representing 1.96 standard deviations from the mean difference are

also shown as the upper and lower horizontal lines. On all plots, the majority of readings were within the LOA, indicating good agreement in readings between the two devices. The readings were also close to the line of equality (zero) indicating there was no systematic bias of one device versus the other. The plots also show that difference between the two readings remained uniform across all the mean values on the X-axis and there is consistent variability. However, the Temp plot shows many outliers, suggesting poor reliability of the BCG



[Table/Fig-9]: Bland-Altman plot of Oxygen saturation (SpO<sub>2</sub>).



[Table/Fig-10]: Bland-Altman plot of Temperature (Temp).

device in measuring Temp. Additionally, the device did not provide corresponding data for 44 out of 1000 monitor readings.

## DISCUSSION

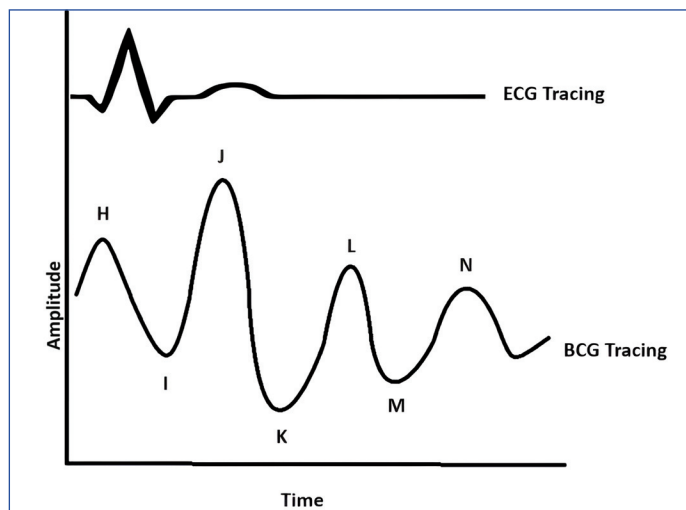
The BCG devices consist of a sensor to pick up the BCG signal, which is sent to a processor that uses specialised algorithms to remove noise and artifacts due to breathing and body movements, and extract vital information, and a monitor to display the vital parameter readings. Most devices such as the Dozee device studied here use Electromechanical film (Emfi) sensors [4]. This is a piezoelectric film, composed of a number of thin polypropylene sheets with air spaces sandwiched between homogenous layers. When external forces are applied on the surface, the width and alignment of the air spaces changes and generate electrical charges.

The patient's sleeping position as well as distance between the sensor and patient's body have a bearing on the measurement [12]. In particular, the prone position might offer a better-quality signal for the heartbeat analysis owing to close approximation of the sensor with the apical impulse of the heart [13]. Hence, the sensor's desired location is under the upper part of the body, placed under the bed sheet or the mattress [14]. Other confounding factors include respiratory artifacts, body movements and type of sensor used, which may affect the accuracy of the readings. In addition, patient agitation and reluctance to be confined to bed may lead to erroneous readings.

BCG has been used in commercial health monitoring systems such as Beddit and Sonomat, both of which are used to measure sleep quality, Murata BCGMCU, HoneyCube and Dozee, amongst many others. These devices vary in the algorithm used to extract a BCG waveform from the body recoil movements as well as in the type of sensor used [15]. For each heart contraction, a BCG waveform is generated [2,16]. BCG is primarily attributed to the interaction of BP at the aortic inlet and outlet as well as the apex of the aortic arch. Hence, the BCG waveform is largely shaped by the aortic BP waveforms [17].

Each waveform is characterised by several peaks and valleys reflecting specific events of the beating heart. However, distinguishing

individual heartbeats is not as straightforward as detecting the sharp QRS complex on an ECG [2]. The BCG waves are named with the capital letters G through O [Table/Fig-11] Waves G to K occur during systole, while the L, M and N waves occur during diastole. Heartbeats may be identified by the J-wave peak in the BCG signal. HR is evaluated by measuring the interval between consecutive J-peaks, the J-J interval [18]. The amplitude of major wave J peak is related to the aortic pulse pressure [7]. The G wave corresponds to atrial systole, H wave to isovolumetric ventricular contraction, I wave to early ventricular systole, J wave to late systole and K wave to end of systole [19,20]. The goal of the machine's algorithms is to automatically identify the "J" peak of the "I-J-K" complex [13].



[Table/Fig-11]: ECG vs BCG waveform.

While a few studies have shown that the Dozee device is accurate at detecting HR and RR [21,22], the present study aimed to validate its accuracy in comparison to a standard Philips MP20 bedside monitor. The results showed that there was significant agreement between the HR, RR, SBP, DBP, MAP, Temp and SpO<sub>2</sub> measured on the Dozee device and the Philips monitor, irrespective of the type of case, by which the null hypothesis could not be rejected. However, reliability of the data was inconsistent, being excellent for DBP, good for HR, moderate for SBP, RR and SpO<sub>2</sub>, and poor for Temp. Also, the device failed to provide data in 44 out of about 1000 (4.4%) corresponding monitor readings, possibly due to dislodgment of the sensors or due to failure of the wireless signal. This risk of device failure can be lessened at the bedside by regular checking of the sensor position, or calibration of the device by comparing with manually measured parameters and ECG. Regular quality assurance practises can be undertaken within a laboratory by applying a quantified external force to the device which mimics displacements caused by the heartbeat, thus standardising the device signal.

The present study shows that this BCG device could be used in environments where a bedside monitor is unavailable or unfeasible, such as in hospital wards, nursing homes and at homes, particularly in situations where patients are confined to their beds. The device also incorporates an Early Warning Score (EWS), where each parameter is allotted a score between 0-3, and if the total is 4 or more, it triggers an alert for immediate attention.

The main drawback is that this machine is applicable only for monitoring patients who are supine in bed for extensive periods. Secondly, there was a variation in reliability noted across various clinical parameters, with accurate readings noted only for HR and BP, while SpO<sub>2</sub> and Temp readings were unreliable. This could be attributed to the core principle of BCG which analyses mechanical and not thermal information. Thirdly, there is a possibility of data being missed, as occurred in about 4.4% of readings in the present study. These factors restrict the use of this device to relatively stable patients who do not require minute-by-minute readings. While

this technology cannot substitute nursing observations, they can be used to monitor trends in vital signs, taking into account their capacity to collect longitudinal data [13]. This is also a cost-effective alternative to a more expensive monitor or a full-time nurse.

### Limitation(s)

This was a single centre observational study over a relatively short period of two months. The sample size was relatively small and could not be met due to logistic reasons. The particular BCG device used here has not been compared to standard monitors previously, and thus this study does not have an established benchmark. The device requires a constant contact with the patient's body, and thus could not be used for scenarios common to the ICU such as haemodynamically unstable or restless patients. Similarly, the practise of regular mobilisation of ICU patients which is a standard of care or bedside procedures limited the use of this device.

### CONCLUSION(S)

The BCG measurement of vital parameters offers a potential contactless method, with reliability varying across parameters. The present study validates the usage of the Dozee BCG device as a substitute for standard bedside monitors monitoring selected vital parameters (HR, BP, and RR), with varying degrees of reliability. BCG remains a fledgling technology which is not foolproof and requires more research and development, to improve accuracy and for more widespread acceptance. At present, the usage of this device remains confined to circumstances where full-time trained personnel at the bedside or a round-the-clock bedside monitor are unfeasible or unavailable. Also, its usage remains limited to patients who are restricted to bed, thus limiting its practical value.

### Acknowledgement

The authors acknowledge Turtle Shell Technologies Private Limited, Bangalore for providing the Dozee BCG devices for the purpose of the present study for a period of two months. The study was conducted and its results were analysed independently.

**Declaration of Interest:** This article was previously presented as a poster at the Indian Society of Critical Care Medicine (ISCCM) National Conference, India on March 1st, 2024.

**Data availability:** The data collected during this study and its results are available for review at 10.6084/m9.figshare.26324203.

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#### PLAGIARISM CHECKING METHODS: [Jain H et al.]

- Plagiarism X-checker: May 09, 2025
- Manual Googling: Feb 06, 2026
- iThenticate Software: Feb 08, 2026 (1%)

#### ETYMOLOGY: Author Origin

EMENDATIONS: 7

#### AUTHOR DECLARATION:

- Financial or Other Competing Interests: None
- Was Ethics Committee Approval obtained for this study? Yes
- Was informed consent obtained from the subjects involved in the study? Yes
- For any images presented appropriate consent has been obtained from the subjects. Yes

Date of Submission: **May 07, 2025**

Date of Peer Review: **Aug 22, 2025**

Date of Acceptance: **Feb 10, 2026**

Date of Publishing: **May 01, 2026**