Evaluation of Non-contact Ballistocardiography as a Screening Method to Determine Systolic Dysfunction and Heart Failure
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Cardiovascular Diseases (CVDs) are the major cause of mortality, in India and world over. Over 420 million cases of CVD and 17 million mortalities were recorded in 2016 all across the world due to CVDs, about 1/3 of all the global deaths [1]. India has a death rate of over 270 deaths per 100,000 population due to CVDs, higher than the global average of 235. The WHO estimated that India would lose $237 billion due to CVDs, from loss of productivity and spending on healthcare, along with 37 million years of life lost due to premature deaths [2].

The reason for such high levels of CVD cases in India is related to diet and lifestyle. Early detection, diagnosis and management of these cases can help in bringing down the burden of CVDs. The increasing population of India and the changing lifestyles requires stepped up focus on measures to counter this epidemic and developing strategies for prevention, early detection and treatment with use of both conventional and innovative techniques. Existing techniques to detect CVDs include electrocardiogram, echocardiography, angiography, catheterization, MRI, blood tests, chest X-Ray and other sophisticated methods. While these are state-of-the-art and gold standard methods, they require highly advanced and expensive machines along with trained personnel and doctors to interpret the reports. A shortage of over 3 million medical professionals [3] poses a multitude of challenges to countering deteriorating health through conventional measures. A screening method to identify CVDs in their early stage can improve patient outcomes.

There are two types of LV heart failure – heart failure with reduced ejection fraction (HFrEF), and heart failure with preserved ejection fraction (HFpEF) – are based on whether the ability of the left ventricle to contract, or to relax, is affected. The scope of this study is limited to systolic dysfunction in HFrEF. LVEF (or EF simply) is the fraction of left ventricular chamber volume ejected during systole (stroke volume) as compared to the volume of the blood in the ventricle at the end of diastole (end-diastolic volume). LVEF is a powerful predictor of cardiac mortality due to systolic heart failure. Accurate measurement of LVEF is crucial in managing patients with CVDs. LVEF has a prognostic value in predicting adverse outcomes in cases with congestive heart failure, after myocardial infarction [4-5]. LVEF measurements can be required for a number of reasons including assessing, patients with signs and symptoms of CVDs, left ventricular function, congenital heart disease and valvular disorders [6].

MPI (Myocardial Performance Index, aka Tei Index) is the fraction of the sum of isovolumetric contraction time (IVCT) and isovolumetric relaxation time (IVRT) to left ventricular ejection time (LVET). A number of studies in the past indicate a clear inverse relationship between MPI and LVEF [7-13]. MPI is an extremely reliable and an early indicator of deterioration in cardiac health. In this study, we propose a novel and innovative method of screening and early detection of HFrEF by calculating the MPI using Ballistocardiography (BCG), a non-invasive technique for measuring micro-body vibrations arising from cardiac contractions [14]. It also contains motion arising from breathing [15], snoring and body movements.

Method
The study was conducted at SJICSR, where 234 subjects were enrolled with varying degrees of systolic dysfunction at a high volume tertiary center. Echocardiography was done on a Philips iE33
Ultrasound Machine by a cardiologist to measure EF and MPI of the subjects. A BCG sensor - Dozee - was also placed under the mattress while the Echocardiography was performed. MPI and associated parameters (MCOT and LVET) were then determined from the BCG Signal independently using a proprietary algorithm.

![Fig 1 (a), Waveform Type 1](image)

![Fig 1 (b), Waveform Type 2](image)

On passing the signal through a 5-25Hz 2nd order Butterworth bandpass filter, broadly, 2 kinds of signal patterns were identified (Fig 1). Phases as shown in the figure were used to find the components used in calculating MPI.

- **Red:** IVCT (Isovolumetric Contraction Time)
- **Green:** LVET (Left Ventricular Ejection Time)
- **Blue:** IVRT (Isovolumetric Relaxation Time)
- **Yellow:** MCOT (Mitrval Valve Closing-Opening Time)

Fig 2 shows the different phases in a complete cardiac cycle for the same heartbeat captured in the BCG and echocardiography data. Subjects were classified into two categories - normal and systolic dysfunction, based on the MPI from BCG. This was compared to the classification on the basis of gold standard - LVEF obtained from echocardiography.

To establish the exclusion criteria and study the effect of other CVDs on the BCG signal and its effect on measuring MPI and associated parameters, subjects with diastolic dysfunction, arrhythmia, valvular disorders were also included in the study.

![Fig 2. Cardiac cycle in echocardiography and BCG](image)

**Results**

The study was conducted on 234 subjects with average age 51.5 (range 18-79). Fig 3 shows the MPI computed from BCG and Ejection Fraction obtained from Echocardiography for all the subjects. Positive case was a subject with EF in Class II (systolic dysfunction) and negative case was a subject with EF in Class I (normal).

<table>
<thead>
<tr>
<th>Index / Class</th>
<th>Class I</th>
<th>Class II</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF</td>
<td>$X \geq 50$</td>
<td>$X &lt; 50$</td>
</tr>
<tr>
<td>MPI</td>
<td>$X &lt; 0.47$</td>
<td>$0.47 \geq X$</td>
</tr>
</tbody>
</table>

The following table shows a confusion matrix for the classification of subjects based on BCG.

<table>
<thead>
<tr>
<th>Condition Positive</th>
<th>Condition Negative</th>
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Classification of subjects into Class I (normal) and Class II (systolic dysfunction) based on MPI obtained from BCG achieved with 91% sensitivity, 83% specificity, 85% accuracy and an ROC-AUC value of 0.86.

<table>
<thead>
<tr>
<th>Predicted Positive</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted Negative</td>
<td>6</td>
</tr>
</tbody>
</table>

Fig 3. MPI plotted against EF from echocardiography

Conclusion
The results indicate that screening for systolic dysfunction and early signs of Heart Failure through BCG sensors is feasible. The classification of subjects into systolic dysfunction and normal categories was performed with a high sensitivity of 91% along with 83% specificity, 85% accuracy and an ROC-AUC value of 0.86. This was based on MPI obtained from BCG considering LVEF from echocardiography as gold standard. The results were similar for subjects with diastolic dysfunction, valvular disorders and arrhythmia. Ease of use, low cost and portability of the BCG sensor makes it a suitable tool to conduct mass screening, especially in resource constrained rural settings. This work also enables monitoring MPI on a regular basis for diagnosed ambulatory CVD patients in home setting to identify early signs of further cardiac deterioration.

Future Work
This study shows the use of BCG for identifying systolic dysfunction in a non contact manner. This work can further be extended to study BCG in other CVDs like diastolic dysfunction, valvular disorders, HfPEF, etc. Similar results can enhance the screening explained in this study into comprehensive cardiac screening. Further, MPI can also be studied while systolic dysfunction progresses to severe categories on a daily basis in the long term in real time.

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