# Assessment of left ventricular mechanics and energetics in various types of left bundle branch block using echocardiography

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## Abstract

**BACKGROUND and AIM:** Recent data suggested that one third of patients meeting conventional electrocardiographic (ECG) criteria for left bundle branch block (LBBB) may be misdiagnosed and new, stricter, ECG criteria for LBBB have been proposed (Strauss's criteria). Accordingly, we used two-dimensional speckle tracking echocardiography (2DSTE), to compare left ventricular (LV) mechanics in patients with LBBB according to conventional versus Strauss's ECG criteria for LBBB.

**METHODS:** We studied 49 asymptomatic patients with incidental LBBB: 16 with conventional (mean age 69 years, 56% were men) and 33 with Strauss's criteria (mean age 66 years, 61% were men), LV ejection fraction (LVEF) ≥45%, and no significant obstructive coronary artery disease. Three-dimensional echocardiography was performed to measure LV end diastolic (LVEDV) and end systolic (LVESV) volumes, sphericity index (SpI), LV remodelling index (LVRI) and LVEF. 2DSTE was used to measure parameters of LV dyssynchrony: septal to posterior wall time to peak radial strain (SW-PW delay), longitudinal strain delay index (L-SDI), longitudinal strain rate dispersion index (L-SRDI) and LV mechanical dispersion (LVMD). In addition, we also measured LV cardiac work indices: global work efficiency (GWE), global work index (GWI), global constructive work (GCW), and global wasted work (GWW).

**RESULTS:** Among dyssynchrony parameters; L-SDI was significantly higher in patients with Strauss's criteria than in conventional one ($37\pm17\%$ vs $25\pm10\%$, respectively, $p = 0.007$). Moreover, GWW tended to be higher in patients with Strauss's criteria than in conventional one ($325\pm132\%$ vs $267\pm124\%$ respectively, $p = 0.079$). In all patients, LVESV index was positively correlated with GWW ($r= 0.51$, $p= 0.001$). This correlation may further support the use of LVESV index change as an echocardiographic predictor to assess LV remodelling after cardiac resynchronization therapy (CRT).

**CONCLUSION:** Patients in whom LBBB was diagnosed according to stricter (Strauss's) ECG criteria showed significantly higher intraventricular dyssynchrony and tendency for higher LV wasted work than patients with LBBB according to conventional ECG criteria. Further studies are needed to assess if the same occurs in patients with LVEF < 35% considered for CRT and further stratification of patients according to ECG pattern may improve the selection of patients who would benefit from CRT.

**Introduction:**

Left bundle branch block (LBBB) is an interruption in the normal electrical sequence of activation of the heart muscle. This is reflected by an abnormal pattern seen on the surface electrocardiogram (ECG). This block may occur along the left bundle branch arising from the His-Purkinje system and may result in various ECG patterns (Siegman-Igra et al., 1978). LBBB may be rarely seen in asymptomatic young individuals with a structurally normal heart (Lamb et al., 1960; Imanishi et al., 2006), but it is often associated with underlying heart disease especially when it is of recent onset. These adverse effects of LBBB may be due to the altered sequence of the electrical left ventricular (LV) activation which is then followed by abnormal sequence of LV mechanical contraction even in the absence of structural heart disease. Investigation of the electrical activation pattern in LBBB patients is limited by the presence of comorbidities and the lack of knowledge regarding the duration and extent of the lesion (or lesions).

Identifying complete LBBB on the ECG is not fully standardized and straightforward. Conventional criteria for LBBB, which are widely used clinically and were applied in large trials. In 2009 American Heart Association, American College of Cardiology Foundation and Heart Rhythm Society suggested updates to the conventional diagnostic criteria of LBBB which additionally included broad notched or slurred R wave in leads I, aVL, V5 and V6 (Surawicz et al., 2009). Strauss *et al.* in 2011 presented new criteria for diagnosing LBBB in which they emphasized that mid-QRS notching is the key feature of LBBB because these notches denote endocardium and lateral LV wall breakthrough of the depolarization wave front (Strauss et al., 2011).

The abnormal and dyssynchronous contraction in patients with LBBB increases the LV work as while some segments contract, they will stretch the not yet contracting segments, thus resulting in energy loss, waste of myocardial work and ineffective LV ejection (Russell et al.,

2013). LV work could be quantified by using a recently developed and validated noninvasive tool namely regional LV pressure – strain loop area (Russell et al., 2012). Along with segmental and global values for myocardial work, a set of additional indices are also calculated (Russell et al., 2012):

1- Constructive work: it is the positive work performed by a segment during shortening in systole in addition to the negative work during lengthening in isovolumetric relaxation (IVR).

2- Wasted work: it is the negative work performed by a segment during lengthening in systole in addition to the positive work performed during shortening in IVR.

3- Myocardial work efficiency: is estimated by dividing the constructive work by the sum of constructive and wasted work (0-100%).

Measurement of regional myocardial electrical–mechanical events using velocity data acquired with tissue Doppler imaging (TDI) showed limitation in assessment of dys-synchrony in patient going to have CRT. To overcome these limitations, new parameters were proposed like, the strain delay index (SDI), strain rate dispersion index (SRDI) and mechanical dispersion (MD).

**Methods**

**Study population:**

We studied 49 asymptomatic subjects with incidental LBBB: 16 with conventional (mean age 69 years, 56% were men) and 33 with Strauss's criteria (mean age 66 years, 61% were men). Thorough clinical history and examination of all subjects were done. Standard 12 leads ECG was done and the subjects classified according to the following criteria as in the following table (1) (Surawicz et al., 2009; Strauss et al., 2011):

**Table (1): ECG criteria for diagnosis complete LBBB in adults**:

| Criteria | AHA/ACC/HRS[*] (conventional) | D. Strauss |
|---|---|---|
| **QRS duration (m/f, ms)** | ≥120/≥120 | ≥140/≥130 |
| **QRS notching or slurring** | Broad notched/slurred R wave in leads I, aVL, V5, and V6 | Mid-QRS notching/slurring in ≥2 of leads V1, V2, V5, V6, I, and aVL |
| **QS or rS in leads V1 and V2** | - | ✓ |
| **Delayed intrinsicoid deflection (>60 ms)** | Present in leads V5 and V6 absent in leads V1, V2, and V3 | - |
| **Usually discordant ST and T wave** | ✓ | - |
| **Q waves in leads I, V5, and V6** | Absent | May present in patients with concomitant anterior and/or apical infarct |

*ACC: American College of Cardiology
*AHA: American Heart Association
*HRS: Heart Rhythm Society

Then computed tomography coronary angiography (CTCA) was done for all subjects. Those

who showed obstructive coronary artery lesions > 50% were excluded.

Then 2D and 3D echocardiographic assessment of all subjects were done with measurement

of:

a. EDV, ESV, LVEF.

b. Global longitudinal strain (GLS).

c. Longitudinal strain delay index (L-SDI).

d. Longitudinal strain rate dispersion index (L-SRDI).

e. Left ventricular mechanical dispersion (LVMD).

f. Septal to posterior wall time to peak radial strain.

g. LV mass, LV sphericity index and LV remodelling index.

h. GWE, GWI, GCW, GWW and WWR.

Standard transthoracic echocardiography was performed using a Vivid E9 and Vivid E 95 ultrasound system, (GE Vingmed Ultrasound AS, Horten, Norway) equipped with a M5S 3.5-mHz transducer.

**Statistical analysis (Leslie et al., 1991)**

Data were expressed as mean ± standard deviation for continuous variables and as percentages for categorical variables. Between-group comparisons were performed using Student's t-tests or x2 test, as appropriate. Statistical significance was defined as $p<0.05$. Statistical analysis was performed using SPSS Version 20.0

**Results:**

In our study; we studied different echo derived intra-ventricular dys-synchrony indices including classic velocity-time delay indices as well as speckle tracking echo (STE) derived indices and correlating them with myocardial segmental work in subjects with different electrocardiographic morphological patterns of LBBB with no under lying significant cardiac disease except for the electrical abnormality. In another words, "pure LBBB". We recruited prospectively 49 consecutive subjects with LBBB and applied manual criteria for differentiation of Strauss apart from conventional patterns. Strauss criteria were applied in about 67.3% versus 32.7% diagnosed with conventional pattern. The mean age of the all subjects in both groups was 66.82 ± 14.1 in our study.

Among dyssynchrony parameters; L-SDI was significantly higher in patients with Strauss's criteria than in conventional one (37±17% vs 25±10%, respectively, p = 0.007) as seen in table (2).

**Table (2):      Comparison between the two studied groups according to L-SDI.**

| | Total (n = 49) | QRS morphology | | Test of Sig. | P |
|---|---|---|---|---|---|
| | | Group I (n = 16) | Group II (n = 33) | | |
| **L-SDI** | | | | | |
| Min. – Max. | 10.29 – 81.11 | 10.29 – 61.88 | 14.26 – 81.11 | U = 138.0* | 0.007* |
| Mean ± SD. | 33.09 ± 17.25 | 24.99 ± 14.26 | 37.02 ± 17.39 | | |
| Median | 27.79 | 19.48 | 33.47 | | |

**U: Mann Whitney test                    t: Student t-test**
 p: p value for comparing between the studied groups
*: Statistically significant at $p \leq 0.05$
**Group I:          LBBB conventional criteria**
**Group II:          LBBB Strauss criteria**

 Moreover, GWW tended to be higher in patients with Strauss's criteria than in conventional

one (325±132% vs 267±124% respectively, p = 0.079, table 3).

**Table (3):      Comparison between the two studied groups according to GWW**

| | Total (n = 49) | QRS morphology | | T | P |
|---|---|---|---|---|---|
| | | Group I (n = 16) | Group II (n = 33) | | |
| **GWW** | | | | | |
| Min. – Max. | 81.0 – 751.0 | 81.0 – 480.0 | 132.0 –751.0 | 1.424 | 0.079 |
| Mean ± SD. | 306.6 ± 133.6 | 267.9 ± 128.3 | 325.3 ± 134.0 | | |
| Median | 300.0 | 254.0 | 316.0 | | |

**t: Student t-test**
p: p value for comparing between the studied groups

**Group I:          LBBB conventional criteria**
**Group II:          LBBB Strauss criteria**

Left ventricular remodelling index (LVRI) and sphericity index (sp. Index) were found to be

positively and negatively -respectively- correlated with GWE, GWI and GCW with statistical

significance only in conventional group and not in Strauss group. While GWW was not found

to be correlated significantly neither with LVRI nor Sp. Index in both groups (table 4). This

means that in patients with conventional criteria of LBBB have better constructive based

global work indices when they have increased LV mass in excess to LV dilatation, probably as

an adaptive mechanism, with less spherical -globular- left ventricular morphology.

**Table (4):     Correlation between global work indices and LV remodelling parameters**

| | GWE | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Total sample (n = 49) | | Group I (n = 16) | | Group II (n = 33) | |
| | R | P | R | P | R | P |
| **LV RI** | 0.324 | 0.031* | 0.542 | 0.015* | 0.205 | 0.523 |
| **Sp. Index** | -0.313 | 0.028* | -0.617 | 0.011* | -0.148 | 0.412 |
| | **GWI** | | | | | |
| | Total sample (n = 49) | | Group I (n = 16) | | Group II (n = 33) | |
| | R | P | R | P | r | P |
| **LV RI** | 0.305 | 0.033* | 0.654 | 0.004* | 0.070 | 0.651 |
| **Sp. Index** | -0.305 | 0.033* | -0.690 | 0.003* | -0.085 | 0.638 |
| | **GCW** | | | | | |
| | Total sample (n = 49) | | Group I (n = 16) | | Group II (n = 33) | |
| | R | P | r | P | r | P |
| **LV RI** | 0.345 | 0.064 | 0.626 | 0.009* | 0.142 | 0.723 |
| **Sp. Index** | -0.241 | 0.096 | -0.704 | 0.002* | 0.005 | 0.976 |
| | **GWW** | | | | | |
| | Total sample (n = 49) | | Group I (n = 16) | | Group II (n = 33) | |
| | R | P | r | P | r | P |
| **LV RI** | -0.131 | 0.254 | -0.081 | 0.657 | -0.196 | 0.401 |
| **Sp. Index** | 0.203 | 0.161 | 0.051 | 0.852 | 0.175 | 0.329 |

**r: Pearson coefficient**
*: Statistically significant at $p \leq 0.05$

**Group I:     LBBB conventional criteria**
**Group II:   LBBB Strauss criteria**

**Discussion:**

Direct assessment of intra-ventricular LV dys-synchrony in LBBB subjects using traditional qualitative parameters namely abnormal segmental motions like septal flash and apical rocking movements in addition to quantitative parameters like septal to posterior wall delay assessed by time to peak radial strain were assessed in both groups. Septal flash assessed visually and confirmed by TDI was found nearly in 80% of the whole cohort while apical rocking movement was found in about 85%. Septal to posterior wall time to peak radial strain was found to be less than 130 milli-seconds (commonly used as a cut off for intra-ventricular dys-synchrony in literature) in all subjects (Pitzalis et al., 2002). Comparing both groups shows no significant difference between them regarding these parameters except for the apical rocking movement was significantly present more in Strauss group than conventional one. These contradictory results of qualitative and quantitative parameters signifying intra-ventricular dys-synchrony urged the need for newer dys-synchrony indices to confirm the coupling of electrical and mechanical dys-synchrony.

In our study we used mechanical dispersion, longitudinal strain delay index and longitudinal strain rate dispersion index as a novel quantitative dys-synchrony index. Prolonged mechanical dispersion reflects increased temporal heterogeneity of myocardial contraction and has been reported to be useful to stratify arrhythmic risk among patients with different cardiac condition (Haugaa et al., 2012; Haugaa et al., 2013; Haland et al., 2016). The mean MD in our study compared to the mean reference value for the same age group as our study population as proposed by Hugo and his colleagues was significantly higher in the whole cohort and consistently higher in both groups as well. The mean in our study was 52.41 ± 14.80 msec while the reference physiological value is 41 ±10 msec (Rodríguez-Zanella et al., 2017). Despite our study did not prove significant difference between conventional and Strauss groups regarding mechanical dispersion; MD was statistically significant negatively

correlated with GWE in conventional group and even with higher significance negatively correlated with GWE in Strauss group. It has had also very significant positive correlation with GWW in both groups. These results render MD - as a dys-synchrony parameter- a good predictor of wasted energy in different subsets of LBBB patients and this of importance considering the results of several studies showing a good correlation between CRT responders and post implantation reduction of MD (Van Der Bijl et al., 2017).

Assessment of longitudinal strain delay index (L-SDI) allowed not only to confirm the dys-synchrony pattern seen in LBBB with delayed post systolic shortening of the lateral segments, but also to quantify the potential wasted energy exerted by these segments contracting while other segments are relaxing. It is worthy to be noted that in our study we measured the strain delay index in both delayed post systolic shortening lateral segments as well as early pre-systolic peaking septal segments as they are both lose their effective contribution to ejection phase. Other studies mainly using L-SDI in patients with cardiomyopathy before CRT implantation; used to mark L-SDI in dys-synchronous segments with positive peaks (stretch) more than their negative peaks (contraction) as zero denoting that they are scarred with no significant contractile reserve (Iwano et al., 2011). We adopted the same concept. However; considering our study group population with isolated LBBB and preserved systolic function we did not encounter such a case. In our study; L-SDI was statistically significant higher is Strauss group than conventional one. Also, it had consistent significant negative correlations with GWE, GWI, GCW and significant positive correlation with GWW rendering L-SDI -as a dys-synchrony parameter- a perfect proof of evidence that Strauss LBBB pattern had lower constructive work and higher wasted work mainly due to its higher dys-synchrony pattern more than conventional LBBB pattern.

The concept of the SRDI is based on the following hypothesis. If LV contraction was synchronized, global LV systolic function will theoretically be equal to the average of

segmental systolic function. Thus, the average of the segmental peak systolic SR, one part of the SRDI, represents the global LV systolic function when contraction is synchronized, whereas global peak systolic SR, the other part of the index, represents that in the presence of dys-synchrony. Therefore, the SRDI, which is the difference between the averaged 18 segments systolic SR and the global LV systolic SR is a direct measure of the magnitude of global dys-synchrony (Marwick, 2006). However; in our study, L-SRDI failed to show significant difference between both groups and failed to show significant correlation with global work analysis parameters.

Direct comparison of both groups regarding global work parameters showed no significant difference regarding GWE, GWI and GCW. This sounded logic considering pre-selection of the whole cohort with preserved ejection fraction and more importantly healthy subjects with no overt, sub clinical heart failure nor associated obstructive coronary artery disease. However; Strauss group tended to have more wasted work than conventional one (P value = 0.079). Indexing the negative work to the positive work to get global wasted work ratio (GWWR) discriminated both groups significantly. Strauss group had significant more GWWR than conventional one (P value = 0.036).

**Study limitations**

One limitation that may influence the strain estimation is the artifacts caused by position shift between breath-holds. This complicates the extraction of the epi- and endocardial surfaces, which are needed for defining the region of interest. All speckle-tracking–derived measurements require more capability in image acquisition and, to obtain correct endocardial border delineation, are contingent on the presence of adequate echocardiographic views. The lack of reference values for remodelling indices, strain parameters (except for GLS), global and segmental work indices makes the use of them a matter of relativity with no absolute cut off values. This needs further large-scale studies to evaluate the physiological determinants of

these parameters in healthy volunteers. Other important limitations of our clinical study include the limited sample size. Further studies including larger sample size applying these parameters and selection criteria on patients with reduced EF candidate for CRT implantation and following up the response can reveal the clinical utility of basic science addressed in our study.

**Conclusion:**

In our study; we found that regardless baseline patient demographic and clinical characteristic; electrocardiographic Strauss LBBB pattern with basic echo study shows large LV volumes, spherical configuration and apical rocking movement denotes more dys-synchrony related wasted myocardial work and energy which can be good target for therapy by means of resynchronization therapy with predictable good response. Conventional LBBB pattern may need further dys-synchrony assessment namely higher mechanical dispersion which correlates significantly with GWE. Therefore, the use of novel echo derived dys-synchrony parameters and myocardial work analysis may further characterize and quantify the magnitude of dys-synchrony and help is selecting candidates for re-synchronization therapy with improved outcome and reducing non responders.

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