# New Insights into Non-Invasive His Bundle Potential Detection on High Resolution Body Surface Recordings

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## Abstract

*This study presents a novel non-invasive method to detect His potentials from high-resolution body surface signals. 35 patients were included in this study. All patients received an invasive electrophysiological study to determine ground truth His-Ventricular (HV) intervals. Prior to these procedures, body surface potentials were recorded using 128 electrodes sampled at 2048 Hz for 8 minutes. Signal averaging was performed on the body surface signals using only the beats occurring during the exhalation phase of respiration. 4 "wide" bipolar (2 electrodes spaced 50 mm) in the vertical, horizontal, right diagonal and left diagonal directions, and Laplacians signals were created and high-pass filtered at 30Hz. Non-invasive HV interval measurements were not performed on 2 (6%) patients because body surface signals were too noisy. His potentials were invisible on the bipolar signals for 5 (14%) patients and on the Laplacian signals for 7 patients (20%). Comparison between invasive (58.5±15ms) and non-invasive HV interval (53.6±14ms) measured with bipolar signals, revealed a squared correlation coefficient (SCC) of 0.66. HV intervals measured with Laplacian signals were less correlated (53.8±18ms) with a SCC of 0.50. This study shows promising results that HV interval can be measured non-invasively using bipolar and Laplacians signals.*

## 1. Introduction

Transcatheter Aortic Valve Implantation (TAVI) is a standard procedure for severe aortic stenosis [1]. Recent studies have demonstrated that atrioventricular (AV) block is one of the most frequent complications of TAVI [2]. The risk of damaging the His bundle and AV node ranges from 4 to 40% [3] and may be higher for patients with pre-existing AV conduction disorders. HV interval measurement is essential for the diagnosis of AV conduction disturbance so as to prevent possible complication of TAVI. The His potential has a very small amplitude (1-4 μV) compared to ventricular depolarisation (1-2 mV) making its detection challenging. Much progress was made in the 70-80's to demonstrate the possibility of detecting the His potential non-invasively using signal averaging [4][5] or a beat-to-beat approach [6][7], but the lack of consistency between the studies does not advocate the use of such methods.

The current method to measure HV interval is invasively using an intracardiac catheter [8]. Because of this, His bundle conduction disorders are only discovered during the TAVI procedure itself.

This study presents a new approach to detect non-invasive HV interval that expands on previous research using a new signal processing workflow based on the use of large localized bipolar and Laplacian signals.

## 2. Materials and methods

### 2.1. Database

35 patients aged 53.1±16.5 years were included. The study was approved by the ethics committee and all patients gave informed consent. For these patients, 17 (49%) were admitted for ventricular fibrillation ablation, 10 (29%) for Steinert disease assessment, 4 (11%) for ischemic ventricular tachycardia ablation, 3 (9%) for syncope assessment and 1 (3%) for premature ventricular contraction ablation.

Invasive recordings were obtained in all patients during an electrophysiology study by inserting a catheter percutaneously into the right femoral vein and advanced fluoroscopically into the right atrium. Ground truth invasive HV interval was measured for each patient by an experienced electrophysiologist.

High resolution body surface signals were recorded using 128 electrodes on the chest, sampled at 2048 Hz for 8 minutes (BioSemi Active Two, the Netherlands). Respiration was recorded simultaneously with a plethysmography belt.

Invasive and non-invasive recordings were performed separately but within a week of each other.

## 2.2. Method

Body surface signals were processed using methods previously outlined in [9]. In brief, a baseline cancellation method based on a wavelet filter was applied and a notch filter to remove 50Hz noise could also be used in appropriate cases. All signals were averaged to decrease the level of noise by a factor of $\frac{1}{\sqrt{N}}$, where N is the number of beats averaged. Only the beats occurring during the exhalation phase of respiration, that is the "flat" phase of respiration, were averaged to avoid signal disturbances due to respiratory motion. Averaging was performed based on the alignment of the QRS of each beat by cross correlation. Noisy signals based on visual inspection were rejected for this study. Four wide bipolar signals were constructed as the difference between 2 signals close to the heart with a 2-electrode spacing (50 mm) to remove far field noise. Bipolar signals were formed in the horizontal, vertical, left diagonal and right diagonal directions (Figure 1). 72 Laplacian signals were also constructed from the 128 body surface signals to enhance singularities and obtain a better spatial resolution (Figure 1). Laplacian signals were computed as the mean of the 8 neighbors of a central electrode minus the central electrode signal. Finally, both bipolar and Laplacian signals were high-pass filtered with a cutoff frequency of 30Hz.

Non-invasive HV interval were measured separately by one blinded electrophysiologist. Variables were reported as mean±SD. Statistical comparisons were performed using unpaired T-test.

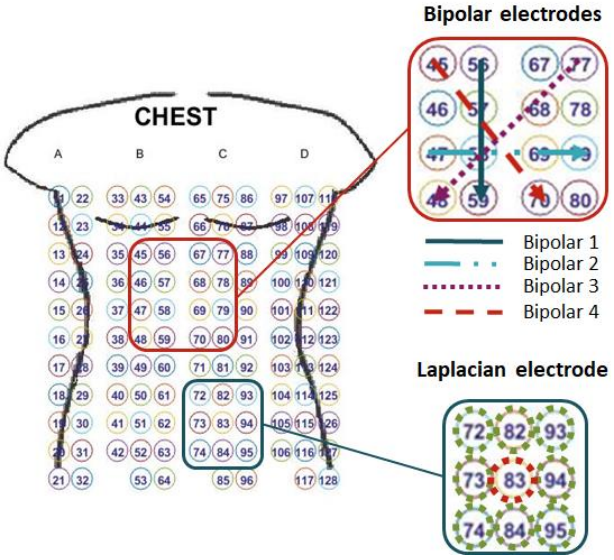


Figure 1: Chest electrode configuration. 72 Laplacian signals were created from the 128 body surface signals (bottom right) by subtracting the mean of the 8 neighbors (green dashed circle) from the central electrode signal (red dashed circle). Four bipolar signals were created (top right) in the 1. vertical, 2. horizontal, 3. right diagonal, 4. left diagonal directions.

## 3. Results

Table 1 sums up the HV intervals obtained for bipolar and Laplacians signals across all patients and their respective noise level. The average number of beats averaged was 193±77 and the PR interval duration was 205±51 ms. The noise level of a signal was calculated using the standard deviation of a 25 ms interval within the ST segment. In Table 1, noise levels were computed using the median and the interquartile of the noise levels over the all bipolar and Laplacian signals for each patient. For two patients (#5 and #29), body surface recordings were too noisy to compute meaningful bipolar or Laplacian signals.

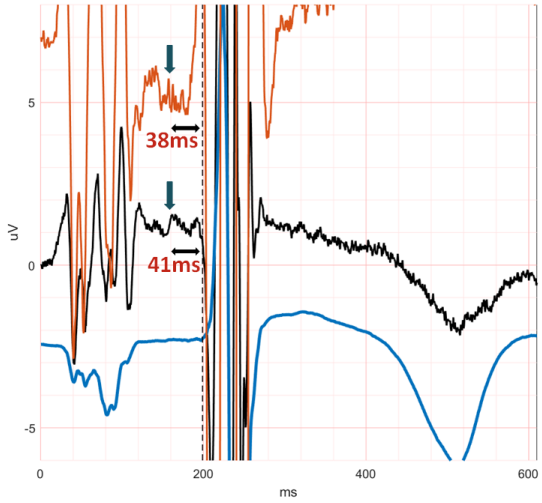


Figure 2: This figure shows Patient #25 filtered bipolar signal 3 (orange signal) and Laplacian signal 49 (black signal) with a bipolar non-invasive HV interval of 38 ms and Laplacian non-invasive HV interval of 41 ms (invasive HV measurement equals to 38 ms) superposed to lead V2 (blue signal).

**Bipolar signals**

Figure 2 presents the filtered bipolar signal 3 (orange), the Laplacian signal 49 (black) and lead V2 (blue) for patient #25. A sharp and fragmented signal (showed by the arrow on the orange signal) with an amplitude of around 0.8 µV was detected during the PR segment in the bipolar signal. The non-invasive bipolar HV interval defined here was equal to invasive measurement (38 ms).

Similar sharp signals during the PR interval could be detected in 28 patients that were close to the timing of the His potential. In five patients, no signal could be detected and instead had a perfect isoelectric line during PR interval. The bipolar His potentials amplitudes were between 0.8-2 µV. The mean value of the non-invasive HV interval was 53.6±14 ms, was close to the invasive HV interval measurements of 58.5±15 ms. The error represented as the absolute value of the difference between invasive and non-invasive HV values was 6.3±6 ms. The mean noise level over all patients was 0.28±0.13 $\mu V$.

Figure 3A shows the linear regression between invasive and non-invasive HV values demonstrating a squared

correlation coefficient (SCC) of 0.66, p=0.58. Figure 3A shows a good repartition of the values around the regression line for invasive HV values inferior to 70ms. However, as HV intervals get longer the points become a little more scattered. 33% of the detected His bundle activity were more visible on the 1st bipolar signal, 20% on the 2nd and 23% for the 3rd and the 4th. Invisible His activity in 3 patients (#1, #2 and #3) was correlated with a long PR (335±22ms). His activity was also invisible in patients #14 and #30 correlated with a level of noise respectively equals to 0.53±0.20 µV and 0.34±0.15 µV.

Tableau 1: HV interval measurements across all patients

| N° | INVASIVE HV (ms) | SURFACE BIPOLAR HV (ms) | SURFACE LAPLACE HV (ms) | BIPOLAR NOISE LEVEL (µV) | LAPLACIAN NOISE LEVEL (µV) |
|---|---|---|---|---|---|
| 1 | 60 | / | 65 | 0.13±0.05 | 0.06±0.03 |
| 2 | 110 | / | / | 0.23±0.05 | 0.16±0.12 |
| 3 | 70 | / | 55 | 0.30±0.20 | 0.12±0.08 |
| 4 | 65 | 80 | 80 | 0.28±0.05 | 0.10±0.03 |
| 5 | 66 | / | / | / | / |
| 6 | 80 | 83 | 110 | 0.10±0.06 | 0.10±0.04 |
| 7 | 59 | 41 | 30 | 0.40±0.50 | 0.08±0.03 |
| 8 | 73 | 77 | 60 | 0.26±0.03 | 0.12±0.07 |
| 9 | 55 | 47 | 45 | 0.26±0.04 | 0.14±0.16 |
| 10 | 58 | 42 | 60 | 0.24±0.07 | 0.07±0.06 |
| 11 | 70 | 64 | 62 | 0.64±0.17 | 0.11±0.07 |
| 12 | 76 | 69 | / | 0.55±0.14 | 0.18±0.07 |
| 13 | 60 | 56 | 50 | 0.27±0.21 | 0.16±0.16 |
| 14 | 76 | / | 90 | 0.53±0.20 | 0.15±0.08 |
| 15 | 50 | 38 | / | 0.23±0.04 | 0.12±0.10 |
| 16 | 64 | 70 | / | 0.20±0.03 | 0.08±0.11 |
| 17 | 52 | 58 | 50 | 0.33±0.17 | 0.10±0.03 |
| 18 | 65 | 62 | 60 | 0.18±0.05 | 0.10±0.03 |
| 19 | 60 | 40 | 47 | 0.26±0.10 | 0.11±0.03 |
| 20 | 44 | 59 | / | 0.25±0.08 | 0.09±0.03 |
| 21 | 48 | 44 | 40 | 0.24±0.06 | 0.11±0.05 |
| 22 | 58 | 55 | 62 | 0.18±0.06 | 0.09±0.03 |
| 23 | 40 | 42 | 42 | 0.23±0.03 | 0.30±0.40 |
| 24 | 42 | 40 | 30 | 0.32±0.07 | 0.17±0.07 |
| 25 | 38 | 38 | 41 | 0.14±0.03 | 0.09±0.07 |
| 26 | 42 | 44 | 44 | 0.16±0.04 | 0.10±0.02 |
| 27 | 44 | 45 | 44 | 0.16±0.03 | 0.08±0.02 |
| 28 | 45 | 43 | 43 | 0.30±0.13 | 0.10±0.03 |
| 29 | 58 | / | / | / | / |
| 30 | 52 | / | / | 0.34±0.15 | 0.10±0.06 |
| 31 | 52 | 47 | 45 | 0.19±0.03 | 0.08±0.04 |
| 32 | 46 | 41 | / | 0.29±0.01 | 0.10±0.05 |
| 33 | 80 | 79 | 50 | 0.39±0.13 | 0.10±0.04 |
| 34 | 40 | 45 | 38 | 0.25±0.07 | 0.12±0.05 |
| 35 | 50 | 52 | 55 | 0.22±0.06 | 0.11±0.05 |

**Laplacian signals**

His bundle activity was detected on Laplacian signals close to the heart from Laplacian 34 to Laplacian 60 (localized on the left side of the chest). Figure 2 shows Laplacian signal 49 (black signal) for patient #25. Here, the His potential (showed by the arrow on the black signal) can be observed with an amplitude of 0.7 µV. The non-invasive Laplacian HV interval (41 ms) was close to the bipolar HV interval and the invasive measurement (38 ms). Overall, the His bundle was invisible on the Laplacian signals of 7 patients. Non-invasive Laplacians HV interval measurement (53.8±18 ms) was computed over the 26 remaining patients. The voltage of the Laplacian His potentials were between 0.7-2 µV. The error between invasive and non-invasive HV values was 9.5±9 ms. The mean value of the noise level over the all patients was 0.10±0.07 $\mu V$.

In figure 3B, non-invasive HV interval measurement were less accurate than with bipolar signals with a SCC of 0.50, p=0.46. Similar findings were seen concerning the repartition of the HV values around the regression line. That is, the dispersion was wider for invasive HV values superior to 70 ms.

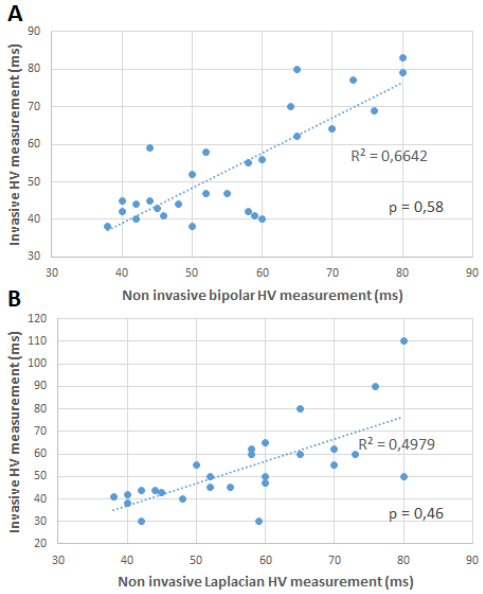


Figure 3: Regression analysis between invasive and non-invasive HV interval measurement for A: bipolar signals and B: Laplacian signals.

## 4. Discussion

This study highlights a new approach to detect non-invasively the His bundle potential based on signal averaging and filtering. This study expands on previous work by selecting only the beats during the exhalation respiration phase to reduce distortions induce by breathing motions. Furthermore, large localized bipolar and Laplacian signals were computed in this new approach to detect the His potential by removing far field noise and enhancing sharp signals. Though the results are promising, its performance was distorted by some limitations.

The results presented are in accordance with previous studies suggesting that the surface His potential is a sharp signal in the range of 1-4µV [10] [11]. Focusing on the bipolar signals, while there was an encouraging correlation between non-invasive and invasive HV intervals (SCC= 0.66), the variability was high. This may be partly due to the lack of knowledge concerning the shape and size of the

His bundle signal on the body surface which may produce mistaken His bundle activity detection. Indeed, for three patients (#1, #2 and #3) the poor detection of the His potential was associated with a long PR conduction disorder (335±22ms). This is often associated with fragmented His potentials on invasive measurements, and may also be the case at the body surface. In total, sixteen patients had a PR interval superior to 200 ms (245±46 ms).

Conversely, when PQ interval was too short atrial activity might overlap with His potential as reported in previous work [5] and thus masked His bundle activity. Another hypothesis relates the possibility that atrial repolarization may deform or mask His potential [10].

Technical limitations due to signal averaging may also explain these observations. While the level of noise is reduced substantially using signal averaging (by a factor of $\frac{1}{\sqrt{N}}$) it may still be too high to detect the very small His potential. For example, in three patients (#7, #11 and #12) though the His potentials were visible, they were incorrectly identified on bipolar signals due to a level of noise equals to 0.53±0.12 $\mu V$. For Laplacian signals however, there appears to be no correlation between HV interval errors and noise level. Alignment perturbation occurring during signal averaging may be another argument to explain the incapacity to detect His potential. This can occur due to an error in the alignment algorithm, or due to physiological noise adding a slight distortion that means the His potential is actually suppressed using beat to beat averaging. Moreover, electrode position on the chest may impact the ability to detect the potentials and as this differs from one patient to another it may affect the quality of His detection. Differences between invasive and non-invasive HV measurements is also human factor dependent. A misplacement of the QRS onset or the His potential may induce a discrepancy while comparing invasive and non-invasive approaches.

Future work will aim at (1) studying a larger number of patients and (2) recording simultaneously invasive and non-invasive His bundle activity to ensure correct alignment and (3) using a simplified model of the His Potential to estimate the torso surface voltage and shape of the His potential according to invasive recordings.

## 5. Conclusion

This study presents a novel approach to detect non-invasively the HV interval using high resolution body surface signals without the need for invasive exploration study. This method is based on selecting the beats during the exhalation phase of respiration and creating large localized bipolar and Laplacian signals to decrease the level of noise and enhance sharp potentials. Though promising results were obtained, future work is needed for His bundle detection in patients with a long PR due to His potential fragmentation and low amplitude.


## Acknowledgments

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