Statistically Evaluation of Mechanical Heart Valve Thrombosis Using Heart Sounds

Sabri Altunkaya, Sadık Kara, Niyazi Görmüş and Saadetdin Herdem

Abstract— Thrombosis is a serious complication and important cause of mortality and morbidity reason for patients with mechanical heart valve. Echocardiogram of mechanical heart valves is necessary to diagnose valve thrombosis definitely. Because of the difficulty in making early diagnosis of thrombosis, and the cost of diagnosis equipment and operators, improving noninvasive, cheap and simple methods to evaluate the functionality of mechanical heart valves are quite significant. In this study, statistical features obtained from auscultation of heart sounds are proposed to evaluate mechanical heart valve thrombosis as a simple method. For this aim, heart sounds of one patient with mechanical heart valve thrombosis and five patients with normally functioning mechanical heart valve were recorded. Statistical features of these sounds, the skewness and kurtosis, were calculated and statistically evaluated using t-test. As a result, it is clearly seen that the skewness of S1 sounds is the most discriminative features ($p<0.01$) and it may be used fairly well in differentiating normally functioning mechanical heart valve from malfunctioning mechanical heart valve.

***Index Terms*— Mechanical heart valve sounds, thrombosis, skewness, kurtosis.**

I. Introduction

Mechanical heart valve thrombosis is any thrombosis attached to a mechanical valve, occluding part of the blood flow or interfering with valvular function [1]. The mechanical heart valve thrombosis is a critical complication relating to the high mortality and requires immediate diagnosis and thrombolytic or surgical treatment [2]. Progression in the structure and design of mechanical heart valve over the years has led to a considerable improvement in their hemodynamic features and durability. However, thromboembolic complications remain a troublesome cause of postoperative morbidity and mortality [3], [4]. According to different literature; incidence of thromboembolic complication ranges from 0.03% to 4.3% patient-years [2], 0.5% to 6% per patient-year [3], 2–4% patients per annum [5] 0.5% patient-years [6] depending on the generation and the thrombosis of the prosthesis used, the location of the valve, and the quality of the anticoagulation [2]. Recently, transesophageal echocardiography has become the gold standard both in the early diagnosis of prosthetic valve thrombosis and in risk stratification for obstruction or embolism in patients with prosthetic heart valves [7]. However, it is quite expensive to use echocardiography for diagnosis of mechanical heart valve thrombosis in the first step medical center because of both a specialist requirement to use echocardiography and cost of these devices. So it may cause misdiagnosis of thrombotic complications in the first step medical center. Therefore, improving noninvasive, cheap and simple methods to evaluate the functionality of the mechanical heart valve are quite important [8]–[11].

There are limited numbers of study to evaluate mechanical heart valve thrombosis using heart sounds and features obtained from frequency and time-frequency analysis of heart sounds are used to detect mechanical heart valve thrombosis in the past studies. In this study, statistical features instead of frequency domain features are proposed to evaluate thrombosis on the mechanical heart valve. For this aim, heart sounds of one patient with thrombosis and heart sounds of five patients with normally functioning mechanical heart valve are recorded. The skewness and kurtosis of heart sounds as statistical features were found and statistically evaluated using t-test.

II. Material and Methods

A. Patients and Data Acquisition

This study includes patients who were operated in the Department of Cardiovascular Surgery, Meram Medical School of Selcuk University. Five patients with normally functioning mechanical heart valve and one patient with mechanical valve thrombosis were selected to evaluate the mechanical heart valve thrombosis using heart sounds. The heart sounds of a patient with thrombosis were recorded before and after thrombolytic treatment. Functionality of the mechanical heart valve of patients was investigated using echocardiography by the physician. After echocardiography investigation, thrombus with partial obstruction was monitored on the mitral mechanical heart valve of a patient. The heart sounds of five patients with normally functioning mechanical heart valve were recorded after the heart valve replacement in one year. The heart sounds of patients recorded from mitral area (intersection of left 5. intercostals interval and mid clavicular line) over the entire course of 30 seconds. All patients had mitral valve replacement and

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clinical in of these patients is shown on Table I.

Table I. Clinical information of patients

Pat. No	Sex	Age	Valve Size	Valve Type	Condition
1	F	58	25mm	Sorin	normal
2	F	27	29mm	Sorin	normal
3	F	35	29mm	Sorin	normal
4	F	30	29mm	St.Jude	normal
5	F	45	29mm	St.Jude	normal
6	F	55	29mm	Sorin	with thrombosis

ECG signals were recorded simultaneously with heart sounds to segment S1 and S2. E-Scope II electronic stethoscope manufactured by Cardionics was used to record heart sounds. Sound signals obtained from electronic stethoscope and ECG signals obtained from the surface electrode were digitized at a 5000 Hz sampling frequency using the Biopac MP35 data acquisition device.

B. Extraction of First Heart Sounds (S1) and Second Heart Sounds (S2)

Before processing of S1 and S2, all recorded heart sounds were filtered with a 30 Hz high pass and 2000 Hz low pass digital finite impulse response filter to get rid of noise. After filtering, the signals were normalized using.

$$HS_{norm}(n) = \frac{HS(n)}{\max|HS(n)|} \quad (1)$$

where HS(n) is the row heart sound signal and HSnorm(n) is the normalized heart sounds signal. Also, a normalizing process was applied to the ECG signal.

Detection of QRS Peaks

QRS peaks of the ECG signal are detected using a first-derivative based QRS detection algorithm. In this algorithm, the ECG signal is first band pass filtered with a pass band of 10-20 Hz to eliminate the baseline wander and high frequency noise. After filtering, the ECG signal is differentiated to obtain QRS-complex slope information, is squared point by point to clarify the R peak in the ECG signal, and then is time-averaged by taking the mean of the previous 10 points. The time-averaged signal is compared to a threshold to obtain the R peak [12], [13]. The threshold is chosen to be a quarter of the maximum time averaged ECG signal. After that, all the RR intervals are compared to 0.5 and 1.5 times the mean RR interval. If the RR interval is longer than 1.5 times of the mean RR interval and is shorter than 0.5 times the mean RR interval, then this RR interval and its counterpart of heart sounds is removed from a signal to prevent wrong detection of RR interval.

Detection of S1 and S2

The ECG signal and Shannon energy is used to detection of the heart sounds. The ECG signal is used as a time reference to determine the time interval where S1 and S2 are searched over one heart cycle. The Shannon energy of heart sounds is used for exact determination of location of S1 and S2 in the finite interval. The Shannon energy of the normalized heart valve sound (HSnormlp) can be calculated using.

$$SE = -\frac{1}{N} \cdot \sum_{n=1}^{N} HS^2_{normlp}(n) \cdot \log HS^2_{normlp}(n) \quad (2)$$

where SE is Shanonn energy of HSnormlp , N is length of recorded data and n is index of HSnormlp [14].

After the Shannon energy of heart sounds is calculated, to determine exactly the location of S1 in the RR interval, the maximum point of the Shannon energy in the interval between 0 01RR. to 0.2 RR is accepted the center of the S1. The maximum point of Shannon's energy between the times the ECG T peaks to the ECG T peak time plus 150 ms is accepted as the center of S2. The duration of S1and S2 was chosen to be 150 ms and 75ms respectively on both sides of the center (Fig. 1).

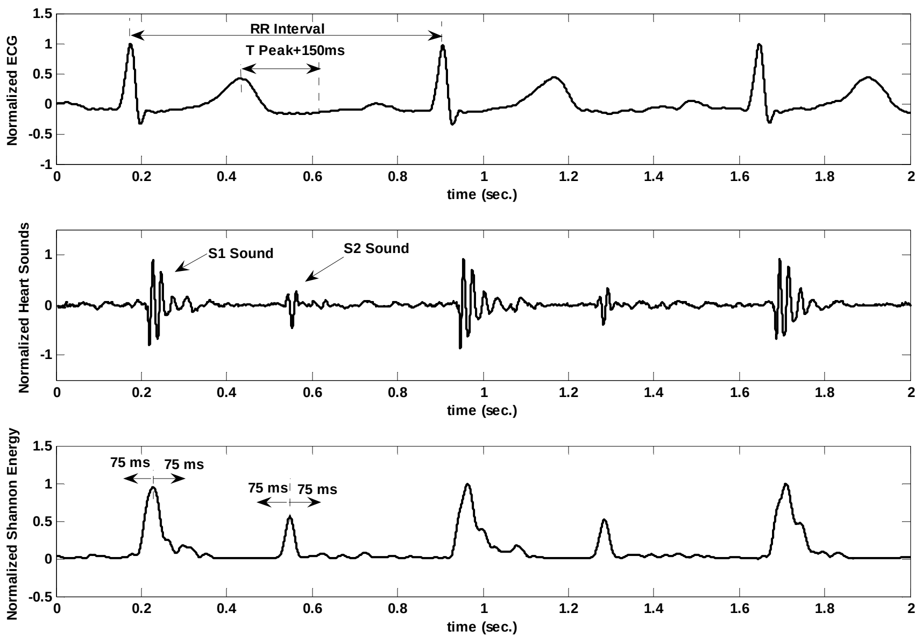

Figure 1. ECG, Heart Sounds and Shannon Energy of One Patient with MVR.

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If the Shannon energy of the right or left side of the center is larger than 40 percent of the maximum Shannon energy, the duration of chosen heart sounds is increased by 20 percent. The comparison is repeated until the Shannon energy of the right or left side of the center is smaller than 40 percent the maximum Shannon energy [15], [16]. In Fig. 1, the upper graph shows the RR interval of the ECG signal, the 0.3-0.65 RR interval, and between the times the ECG T peaks to the ECG T peak time plus 150 ms, the middle graph shows the heart sounds signal, and the bottom graph shows the calculated Shannon energy.

C. Skewness and Kurtosis

The change in the distribution of the signal segments is measured in terms of the skewness and kurtosis. The skewness characterizes the degree of asymmetry of a distribution around its mean. The skewness is defined for a real signal as

$$Skewness = \frac{E(x-\mu)^3}{\sigma^3} \tag{3}$$

where μ are the mean and σ are the standard deviation and E denoting statistical expectation? The skewness shows that the data are unsymmetrically distributed around a mean. If the distribution is more to the right of the mean point the skewness is negative. If the distribution is more to the left of the mean point the skewness is positive. The skewness is zero for a symmetric distribution. The kurtosis measures the relative peakedness or flatness of a distribution. The kurtosis for a real signal x(n) is calculated using

$$Kurtosis = \frac{E(x-\mu)^4}{\sigma^4} \tag{4}$$

where μ are the mean and σ are the standard deviation and E denotes statistical expectation. For symmetric unimodal distributions, the kurtosis is higher than 3 indicates heavy tails and peakedness relative to the normal distribution. The kurtosis is lower than 3 indicates light tails and flatness [17], [18].

III. Result and Discussion

There are approximately 30 first heart sounds (S1) and 30 second heart sounds (S2) component in thirty second recording of heart sound of each patient. The skewness and kurtosis of this entire S1 and S2 component were calculated for all recorded heart sounds. Table II shows mean and standard deviation (std.) of the skewness and kurtosis of the heart sounds of one patient with mechanical heart valve thrombosis(Thr), the heart sounds of the same patients after thrombolytic treatment (ATr) and the heart sounds of five patients with normally functioning mechanical heart valve(N). Fig. 2 illustrates the summary statistics for the skewness and kurtosis of S1 and S2 of Thr, ATr and N.

Table II. Mean ± Standard deviation(std.) of the skewness and kurtosis

	Thr (mean±std.)	ATr (mean±std.)	N (mean±std.)
Skewness of S1	0,96±0,36	0,18±0,25	0,12±0,42
Skewness of S2	0,71±0,7	0,3±0,36	-0,2±0,54
Kurtosis of S1	5,24±1,11	4,34±0,45	5,9±1,75
Kurtosis of S2	8,39±2,47	5,65±1,56	5,79±1,92

Thr : Patient with mechanical heart valve thrombosis,
ATr : Patient with mechanical heart valve thrombosis after thrombolytic treatment,
N : Five patient with normally functioning mechanical heart valve.

From Table III and Fig. 2, it can be said that there are a meaningful differences between means of the skewness of S1 and S2 and S2 of the kurtosis of heart sounds of patients with normally and malfunctioning mechanical heart valves. The kurtosis of S1 has the similar mean for these heart sounds. However, it is clearly seen that the skewness of S1 is the best feature to show difference between the normally and malfunctioning mechanical heart valve.

Paired t-test with 99% confidence level was used for comparison means of the skewness and kurtosis between heart sounds of a patient before and after thrombolytic treatment was administered. Unpaired t-test with 99% confidence was used for comparison means of the skewness and kurtosis between patients with normally functioning mechanical heart valve and patient with mechanical heart valve thrombosis (before treatment). These tests were applied to two features, the skewness and kurtosis, obtained from two sound components S1 and S2. p value obtained from above tests is shown on Table III.

The skewness of S2 only between Thr and N, the kurtosis of S1 only between Thr and ATr, the kurtosis of S2 only between Thr and N shows statistically significance differences ($p<0.01$). But the skewness of S1 shows statistically significance differences both between Thr and ATr and between Thr and N ($p<0.01$). Because of this, the skewness of S1 is the best feature to distinguish heart sounds of a patient with mechanical valve thrombosis and normally functioning mechanical heart valve (Table III).

Although there are limited numbers of studies about frequency spectrum of mechanical heart valve sounds, it is known that thrombosis formation on a prosthetic heart valve changes the frequency spectrum of both biological and mechanical heart valve. In these studies, generally modified forward-backward Proony's Method was used to detect frequency component of prosthetic heart valve [8]–[10], [19], [20].

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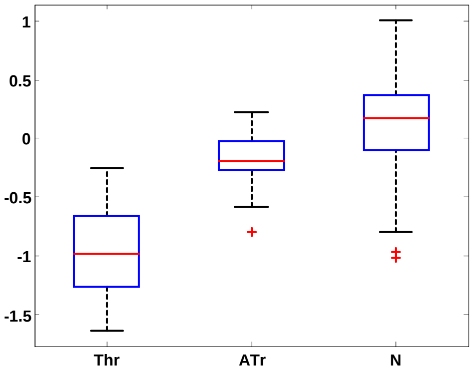
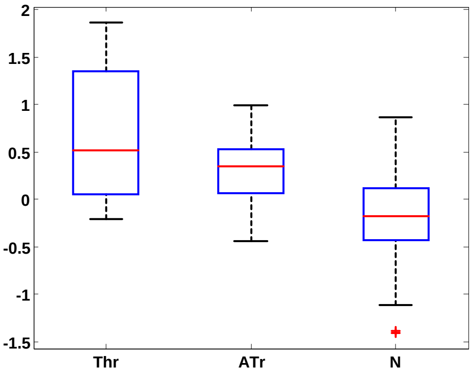
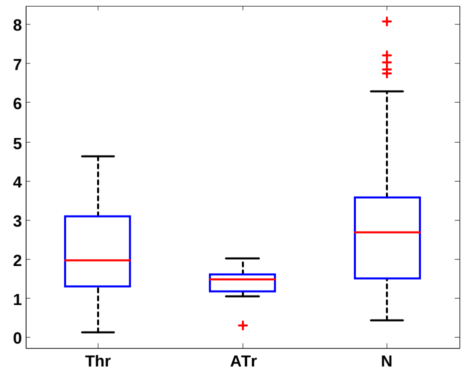


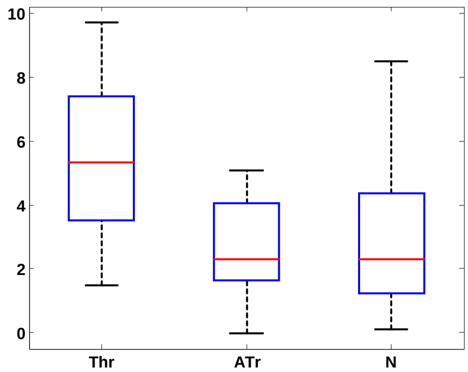
(a) Skewness of S1



(b) Skewness of S2



(c) Kurtosis of S1



(d) Kurtosis of S2

Figure 2. a. Box plot for the skewness data of S1 b. box plot for the skewness data of S2 c. box plot for the kurtosis data of S2 d. box plot for the kurtosis data of S1(Thr: patient with mechanical valve thrombosis, ATr: patient after thrombolytic treatment and N: five patients with normally functioning mechanical valve)

Table III. p value obtained from paired and unpaired t-test.

	Between heart sounds of Thr and ATr (paired t-test)	Between heart sounds of Thr and N (unpaired t-test)
Skewness of S1	0.0000018	0.000006
Skewness of S2	0.0199	0.0011
Kurtosis of S1	0.0046	0.0712
Kurtosis of S2	0.0016	0.0924

Thr : Patient with mechanical heart valve thrombosis,
ATr : Patient with mechanical heart valve thrombosis after thrombolytic treatment,
N : Five patient with normally functioning mechanical heart valve.

In our study, the skewness and kurtosis of heart sounds of patients with mechanical heart valve thrombosis and normally functioning mechanical heart valve were compared statistically. As a result, the skewness of S1 of mechanical heart valve should perform fairly well in differentiating normally functioning and malfunctioning mechanical heart valve. However, effectiveness of the skewness of S1 to detect malfunctioning mechanical heart valve should be proven with a large patient population. After that, the skewness of S1 of mechanical heart sound signals may be used for analysis of mechanical heart valve sounds with a view to detecting thrombosis formation on mechanical heart valve.

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