Investigation of the Effect of Diabetes on Lower Limb Muscles with Surface Electromyography (EMG)

Mahmoud I. Al-Kadi[1]
{mahmoudalkadi67@kecbu.uobaghdad.edu.iq/mahmoudalkadi67@yahoo.com}

Biomedical Engineering Department, Al-Khawarizmi College of Engineering, University of Baghdad[1]

Abstract. The ELECTROMYOGRAM (EMG) is a signal that indicates the muscle power and strength, It varies according to its type, location, and size of the muscle and other effectors, and in this project, it shows the muscle also affected by diseases like diabetes. The signals recorded were about 20 signals of cases (10 signals for normal cases and 10 signals for diabetes patients) after choosing three muscles in the lower limb (vastus lateralis (VL), TIBIALIS ANTERIOR (TA), and GASTROCNEMIUS medialis (GM)), each case apply three tests (standing, walking and stand over one foot) to know when the muscle affected greatly in which test and when the fatigue occurs. These signals were filtered carefully to eliminate the interface of other signals using three different stages according to the EMG frequencies (0.1 - 450) Hz. Three kinds of features were extracted (mean, standard deviation, and Shannon entropy) from EMG signals. The results show the variance between control muscles and patient muscles in amplitude and power where this variance increases whenever the duration and severity of the diabetes are increased.

Keywords: Diabetes, Muscles, EMG, Features.

1 Introduction

The muscular system is in charge of the human body's mobility. About 700 identified muscles are attached to the bones of the skeletal system, accounting for nearly half of a person's total weight. Each muscle is a separate organ made up of skeletal muscle tissue, blood vessels, tendons, and nerves [1]. The muscular system's tasks include movement, vasoconstriction and vasodilatation (constriction and dilation of blood vessel walls), peristalsis (wavelike motion in the digestive tract), and vasodilatation (constriction and dilation of blood vessel walls). Cardiac motion, posture maintenance (skeletal muscle activation maintains body posture and muscular tone), and heat generation (about 75% of ATP (adenosine triphosphate) energy required in muscle contraction is dissipated as heat). Skeletal muscle, smooth muscle, and heart muscle are the three types of muscles [2].

Diabetes, for example, damaged the muscle and the nerve that supplied it. Diabetes mellitus is a collection of metabolic illnesses defined by high blood sugar levels (hyperglycemia) caused by insulin secretion, insulin action, or both. Chronic hyperglycemia has been linked to microvascular and macrovascular consequences, including blindness, renal disease, nerve damage, amputations, heart disease, and stroke [3].

Type I diabetes is caused by a lack of insulin production in the body, necessitating daily insulin injections. Type II diabetes is caused by a lack of insulin production in the body, necessitating

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daily insulin injections. This type is caused by the immune system attacking the pancreas' beta cells. This variety can appear at any age, however it is more prevalent throughout childhood and adolescence. Genetic predisposition and environmental triggers (infection or stress) are contributing variables in the emergence of these kinds [4]. Type II diabetes develops when the body fails to produce enough insulin. Reduced food intake, greater physical exercise, and finally oral medicines or insulin are used to treat high blood glucose levels. Many factors contribute to this category. First, there's insulin resistance in the liver and skeletal muscle, as well as increased glucose production in the liver, fat cell overproduction of free fatty acids, and insulin insufficiency. Second, as beta-cell loss progresses, insulin secretion diminishes. Obesity, age, and lack of physical exercise, genetic susceptibility, and conditions associated with insulin resistance are all contributing factors that lead to this type of diabetes [5]. Gestational diabetes is the last kind of diabetes. When a lady gets pregnant, this kind appears. Insulin resistance can be caused by hormones produced by pregnant women. Late in pregnancy, all women develop insulin resistance. Gestational diabetes develops when the pancreas does not produce enough insulin during pregnancy. Women who are overweight or obese are more likely to develop gestational diabetes. Additionally, gaining too much weight during pregnancy may increase your risk of gestational diabetes. After the baby is born, gestational diabetes usually goes away. A woman with gestational diabetes, on the other hand, is more likely to develop type I diabetes later in life. Obesity and type diabetes are more frequent in babies delivered to mothers who had gestational diabetes. All of these types are divided into three categories: mild, moderate, and severe [3,6,7].

2 Muscle and Diabetes

Type I Diabetes Mellitus (TIDM) impairs muscle growth and development, resulting in decreased muscle mass and myofiber size, poor metabolic regulation, and a switch to a glycolytic phenotype. While initial human TIDM research found no differences in capillary density, studies in TIDM animals show that the disease is linked to a decrease in skeletal muscle capillarization and angiogenesis [8]. As previously demonstrated, changes in muscle structure and metabolism are frequently associated with reductions in muscle function. In addition to growth and function, TIDM has been shown to impair the ability to repair damage, as evidenced by studies of muscle regeneration using chemical and genetic models of TIDM. Overall, these investigations show that TIDM has a deleterious influence on skeletal muscle and its ability to grow, maintain, and repair [9]. Muscle growth and development are significantly impaired in Type I Diabetes Mellitus (TIDM), resulting in reduced muscle mass and myofiber size, poor metabolic control, and a switch to a glycolytic phenotype. While initial studies in human TIDM reported no difference in capillary density, investigations in TIDM mice illustrate that the disease is associated with a decline in skeletal muscle capillarization and angiogenesis These alterations to muscle structure and metabolism often are associated with reductions in muscle function, as previously demonstrated in addition to growth and function, the capacity for repair from damage is also adversely affected by TIDM, as indicated by studies of muscle regeneration using chemical and genetic models of TIDM Collectively, these studies highlight the negative impact TIDM is having on skeletal muscle and its potential for growth, maintenance, and repair. Muscle atrophy can be caused by a variety of factors, including extended inactivity, ageing, and chronic diseases like Type II Diabetes Mellitus (TIIDM). Muscle atrophy occurs when the pace of contractile protein production and breakdown is out of equilibrium. Muscle atrophy

combined with inactivity can reduce the ability to perform everyday activities, lower quality of life, and increase mortality under catabolic situations. Damaged or unfolded proteins must be degraded in order to maintain cellular homeostasis in healthy muscle. However, in atrophic situations such as disuse or diabetes, persistent elevated activity of these pathways increases the rate of contractile protein breakdown, eventually leading to muscle atrophy and decreased protein synthesis [10].

3 Methodology

This section illustrates the steps adopted as shown in figure 1. The recorded EMG data are divided into two types: data acquired from a group of diabetic's patients aged 20-60 years in different levels of diabetes while the other data was acquired from normal persons (as control signals). Some of the patients had severe diabetes (treatment through the injection of insulin) and others had recently been diagnosed with diabetes ((treatment through tablets). The consent form and the agreement were taken from the patients before recording their EMG signals for scientific research.

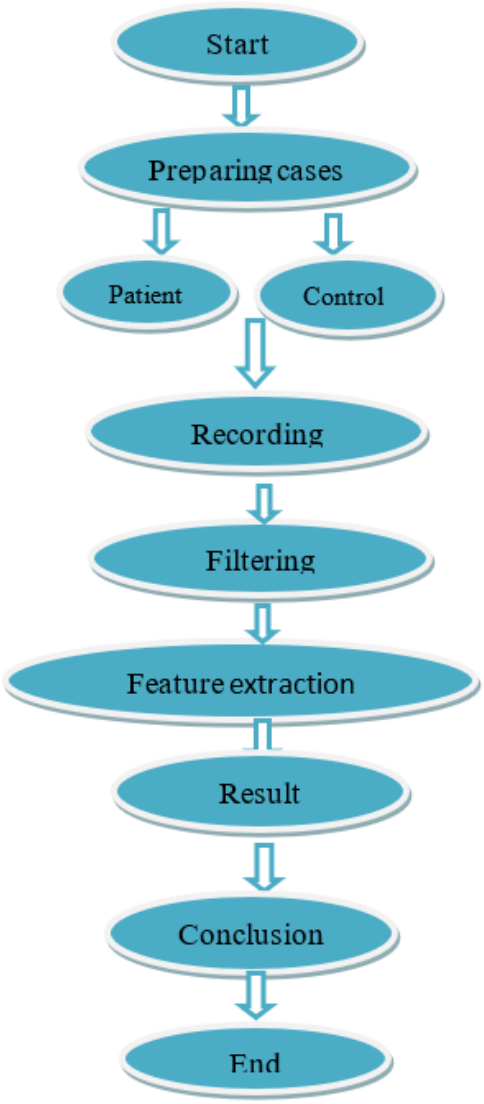


Fig.1. The steps of the methodology.

4 Acquiring the EMG Signals

MyoTrace 400 was used for recording the EMG signals with three channels. The goal of this system is to measure and quantify muscle biopotential signals alone or in combination with other kinematic signals. Channels 1,2 and 3 are connected to the EMG electrodes on the patient muscles in the locations tibialis anterior (TA), gastrocnemius medialis (GM) and vastuslateralis (VL) respectively for one lower limb while the ground electrodes were connected to the knee bone as shown in figure 2 [11,12].

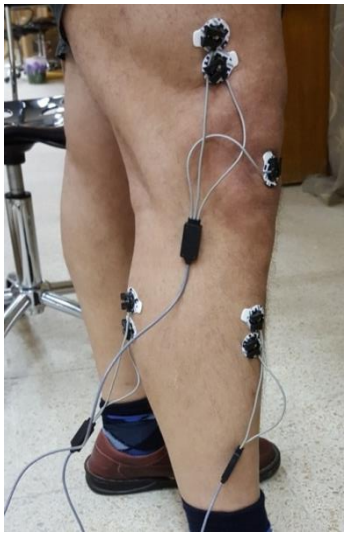


Fig 2. The location of EMG electrodes.

The EMG signals were recorded from 20 samples, 10 signals for normal cases and 10 signals for diabetes patients. Each signal is recorded with the following sequence: stand on a single foot for 1 minute, walk for 5 minutes, stand for 1 minute then record another 5 minutes [13]. All recorded EMG signals were acquired in biomedical labs of Al-Khwarizmi College, Baghdad University. This research was committed based on ethical process of the University of Baghdad. The ethics approval is taken before recording the EMG signal. The study also conforms to the principles of the Declaration of Helsinki (Good Clinical Practice (GCP) 2008), which is the declaration on ethical principles in conducting human trials, adopted at the 18th World Medical Association (WMA) held at Helsinki, Finland in 1964 [14,15].

5 Feature Extraction

The features are chosen carefully according to their ability to describe the muscle signal changes at different levels of diabetes, considering the execution speed and the efficiency in classifying the EMG signals. Some of these features depend on sub-band coefficients, while the others depend on the wave of the sub-bands (i.e., reconstruction of the sub-band to generate a new time series for each sub-band) [16,17,18].

5.1 Mean Square Error (MSE)

This criterion is used to follow the variation of EMG bands after removing the noise and artifacts that overlapped with the time-series elements. This feature is defined as follows:

$$MSE = \frac{1}{N}\sum_{n=1}^{N}[(x(n) - \hat{x}(n)]^2 \quad (1)$$

where$x(n)$is the contaminated time series and $\hat{x}(n)$ is the filtered time series.

5.2 Standard Deviation of the Wavelet Coefficients (SD)

This feature calculates the standard deviation of each EMG. The variation of this feature is utilized to follow the level of diabetes.

$$STD = \left(\frac{1}{NS-1}\sum_{i=1}^{NS_{jk}}(x_i - \bar{x})^2\right)^{\frac{1}{2}} \quad (2)$$

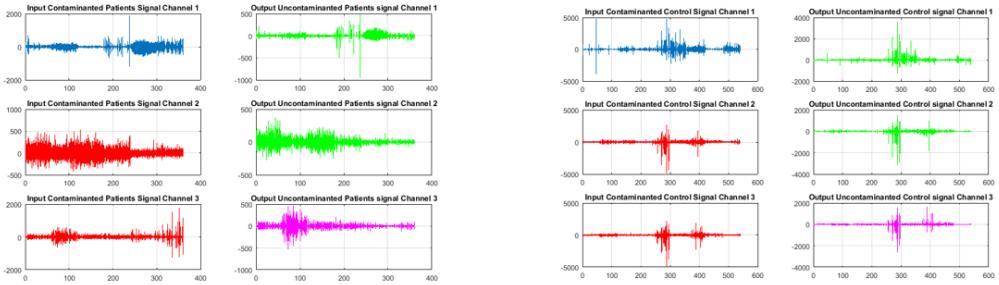
5.3 Time Series Shannon Entropy

Shannon entropy is the first concept of entropies in information theory literature. This type of entropy is used to quantify the disorders in the time series and to measure the flatness of the energy spectrum in the wavelet domain. This entropy quantifies the regularity of a time series and predicts new values according to previous observations. The probability density function of Shannon entropy "ShaEnt" was calculated:

$$ShEn_{jk} = -\sum_{n=1}^{NS_{jk}} p_{jk} \ln p_{jk} \quad (3)$$

6 Results and Discussion

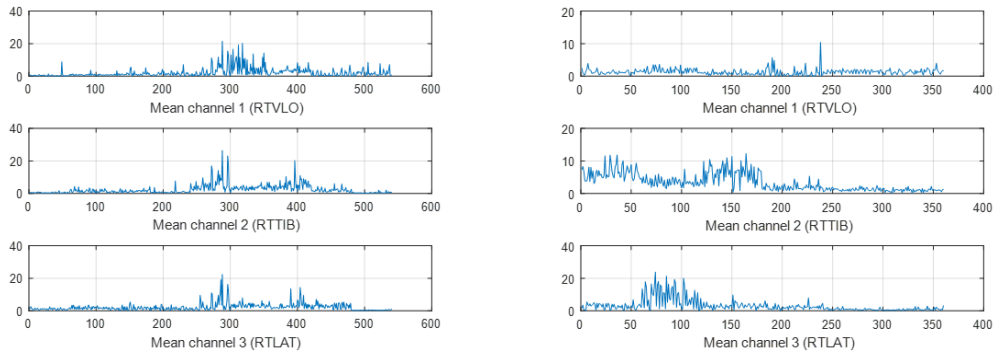
Ascertaining the effectiveness of denoising techniques, feature extraction, and EMG signal classification is of prime importance. This section describes the validation process for the proposed methodologies. The methodologies that were employed to characterize the EMG signals for the muscle that is affected by a chronic disease such as type I and II Diabetes Mellitus (TIDM /TIIDM) were validated by using the data that were acquired in the lab of Al-Khwarizmi engineering college. The first stage of signal processing of the recorded signal is the noise removal process. This stage includes three sub-stages to remove the noise and artifacts from the recorded EMG signals. Conventional filters are the first approach that is used to denoise the EMG signals which consist of two types of filters: notch filter (NF) and bandpass filter (BPF). NF is used in all EMG recording devices to eliminate the effects of the AC line and its harmonics (50 Hz). This filter ensures the complete removal of this type of noise from the frequency of EMG signals. BPF with order 4 has been used to specify the effective frequencies that represent an EMG signal, which is confined between 50 and 450 Hz. The filter also removes the DC level that is generated by electronic equipment. The third filter is a wavelet filter. This technique removes artifacts that overlapped with the recorded EMG signals. In this work, the three channels of EMG signals are filtered by this technique second by second using MWT db4 with order 4. Figure 3a shows the three channels of EMG signals before and after undergoing the NF, BPF, and WT denoising process of the control signals. Figure 3b shows the three channels of EMG signals before and after undergoing the BSF, BPF, and WT denoising process of the patient's signals. The most of artifacts and noise that overlapped with the recoded signal are removed without affecting the details of the EMG signals.



(a) **(b)**

Fig.3. Three channels of the EMG signal filtered by NF, BPF and WT technique (a) Control signals (b) Patients signals.

As mentioned before, three features were extracted from the EMG signal. All functions were chosen carefully according to their ability to describe the EMG signal changes when the power of the muscle due to diabetes. All features were extracted from EMG signal second by second. These features are Mean (MEAN), Standard deviation (STD), and finally Shannon entropy (ShaEnt). The next section will discuss these features for both (control signals and diabetes signals) for finding the effect of this disease on the effectiveness of the muscle. According to Figure (4), the mean value for each second rises by (40mv) in the healthy muscles (control signal) while the mean value of the EMG signals is reduced to (20mv) in the infected muscles. this feature gave good evidence that the muscles are affected efficiently by diabetes where the EMG signals are reduced with the severity of the disease.

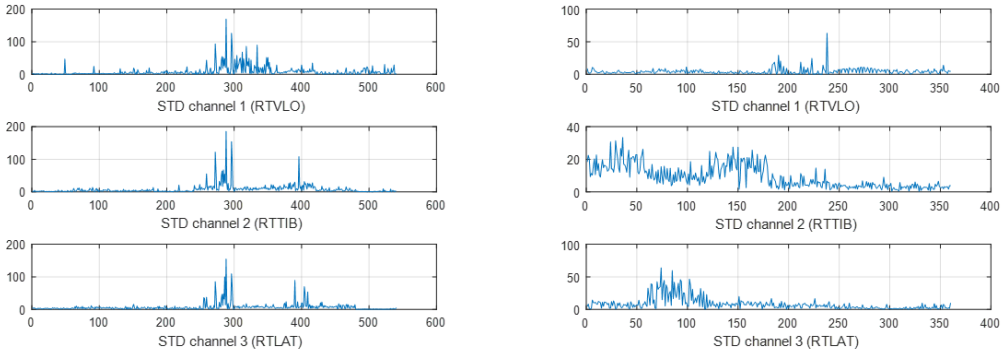


(a) **(b)**

Fig.4. The Mean of three channels of the EMG signal
(a) Control signals (b) Patients signals.

The standard deviation (SD) is one of the best ways to determine the dispersion. It is based on calculating the deviation from the average either by divergence or convergence. Figure (4) shows the deviation for normal muscles and infected muscles. Figure 5a shows SD of the normal muscle where it is normally distributed around the mean and the sample value is reached to (200) while the deviation values for the infected muscles are less than (100) and not distributed

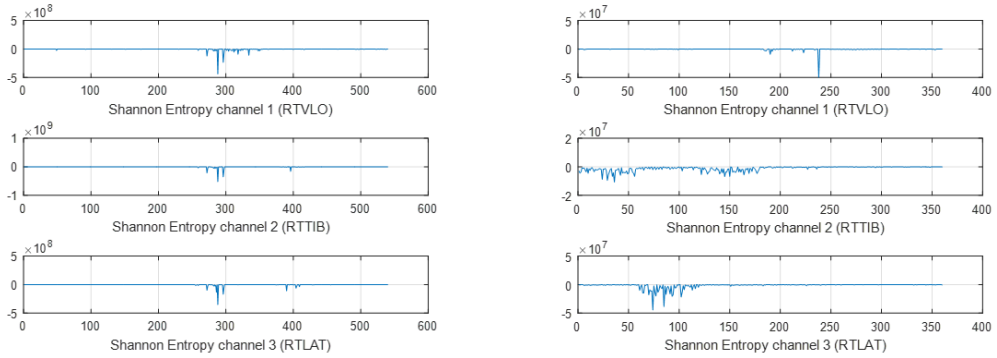
around the mean (chaotic signal) as illustrated in figure 5b. In the same meaning, the signal of the infected muscles has many variations along the time comparing with normal muscle.On the other side, this feature didn't observe a significant variation in channel one that means the Vastus lateralis muscle (RTVLO) does not have essentially affected by diabetes.



(a) **(b)**

Fig.5. The standard deviation of three channels of the EMG signal
(a) Control signals (b) Patients signals.

Generally, the entropy function is used to illustrate the randomness of the samples of the recorded signals. Figure 6a shows the Shannon entropy of the control signal while figure 6b shows the signal entropy of the infected muscles. these figures show the disparity between the entropies where the entropy of the control signal gives a high distribution and higher in value (10^8) while the entropy of the that recorded from the infected muscle low distribution and lower in value (10^7) (weak muscles) which means the muscles would work regularly when they are not affected by diabetes.



(a) **(b)**

Fig.6. The Shannon Entropy of three channels of the EMG signal
(a) Control signals (b) Patients signals.

6 Conclusion

After observation of the results and figures, it is clear that the muscle of diabetes mellitus has been affected by a significant impact as the muscle tends to lose or damage, as the reduction of the effectiveness of insulin increases the level of sugar and lose muscle insulin effect, which strengthens and rebuild, and the real problem of the disease that the patient gradually loses the ability to move, that he suffers wasting reduces movement and prevents him from serving himself and even from the work of exercises that strengthen his muscles.

References

[1] Dr.Ebneshahidi , Muscle Physiology, 2004 Pearson Education, Inc., publishing as Benjamin Cummings.

[2] Anne Buckley MD PhD Neuropathology, Diseases of Skeletal Muscle,2004.

[3] Emily Loghmani ,diabetes mellitis: type 1 and type 2, 2005.

[4] American Diabetes Association.Economic consequences of diabetes mellitus in the U.S. in 1997. Diabetes Care 1998;21(2):296-309.

[5] Rosenbloom AL, Joe JR, Young RS, Winter WE. Emerging epidemic of type 2 diabetes in youth. Diabetes Care 1999;22(2):345-354.

[6] Pinhas-Hamiel O, Dolan L, Daniels SR, Standiford D, Khoury PR, Zeitler P. Increased incidence of noninsulin-dependent diabetes mellitus among adolescents. J Pediatr 1999;128:608-615.

[7] American Diabetes Association.Type 2 diabetes in children and adolescents.Pediatrics 2000;105(3 Pt 1):671-680.

[8] H Yki-Järvinen [1], H Vuorinen-Markkola, L Koranyi, R Bourey, K Tordjman, M Mueckler, A M Permutt, V A Koivisto, Defect in Insulin Action on Expression of the Muscle/ Adipose Tissue Glucose Transporter Gene in Skeletal Muscle of Type 1 Diabetic Patients , Journal of Clinical Endocrinology and Metabolism, 1992 Sep;75(3):795-9. doi: 10.1210/jcem.75.3.1517369.

[9] Santos, A. J. C. A., Silva, E. L. A., Albuquerque, Y. M. L., Oliveira, B. D. R. and Caiaffo, V., Effects of diabetes mellitus type I on skeletal muscle: an integrative review, Journal of Morphological Sciences 33(2):118-120 · January 2016

[10] Jing He and David E. Kelley, Muscle glycogen content in type 2 diabetes mellitus, Department of Medicine, University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania, 1 July 2004.

[11]Ricky Watari1 , Cristina D Sartor1 , Andreja P Picon1 , Marco K Butugan1 , Cesar F Amorim2 , Neli RS Ortega3 and Isabel CN Sacco, Effect of diabetic neuropathy severity classified by a fuzzy model in muscle dynamics during gait, Journal of NeuroEngineering and Rehabilitation 2014, 11:11.

[12] Perry BD, Caldow MK, Brennan-Speranza TC, Sbaraglia M, Jerums G, Garnham A, Wong C, Levinger P, AsrarUlHaq M, Hare DL, Price SR, Levinger I , Muscle atrophy in patients with Type 2 Diabetes Mellitus: roles of inflammatory pathways, physical activity and exercise, ExercImmunol Rev. 2016; DOI:22:94-109.

[13] Sacco IC, Amadio AC: Influence of the diabetic neuropathy on the behaviour of electromyographic and sensorial responses in treadmill gait. ClinBiomech (Bristol, Avon) 2003, 18(5):426–434

[14] Kwon OY, Minor SD, Maluf KS, Mueller MJ: Comparison of muscle activity during walking in subjects with and without diabetic neuropathy. Gait Posture 2003, 18(1):105–113

[15] Petrofsky J, Lee S, Bweir S: Gait characteristics in people with type 2 diabetes mellitus. Eur J ApplPhysiol 2005, 93(5–6):640–647.

[16] Gomes AA, Onodera AN, Otuzi ME, Pripas D, Mezzarane RA, Sacco IC: Electromyography and kinematic changes of gait cycle at different cadences in diabetic neuropathic individuals. Muscle Nerve 2011, 44(2):258–268.

[17] Sawacha Z, Spolaor F, Guarneri G, Contessa P, Carraro E, VenturinA, Avogaro A, Cobelli C: Abnormal muscle activation during gait in diabetes patients with and without neuropathy. Gait Posture 2012, 35(1):101–105.

[18] Jason L. Rucker, Stephen D. Jernigan, Joan M. McDowd and Patricia M. Kluding,Adults with diabetic perfral neuropathy exhibit impairments an multitasking and other executive functions , J NeurolPhysTher. 2014 Apr; 38(2): 104–110.