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FATIH UNIVERSITY
INSTITUTE OF BIOMEDICAL ENGINEERING

ANALYZING EMG SIGNAL OF JAW MUSCLES BY USING EMD AND SVD TO DETECT THE EFFECT OF MISSING TEETH ON CHEWING PERFORMANCE

MÜJDE ALLI

MSc THESIS
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FATİH ÜNİVESİTESİ
BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

DİŞ KAYBININ ÇİĞNEME PERFORMANSI ÜZERİNDEKİ ETKİSİNİ SAPTAMAK İÇİN ÇENE KASLARINDAN ALINAN EMG SİNYALLERİNİN EMD VE SVD KULLANILARAK ANALİZ EDİLMESİ

MÜJDE ALLI

YÜKSEK LİSANS TEZİ
BİYOMEDİKAL MÜHENDİSLİĞİ PROGRAMI

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İSTANBUL, HAZİRAN / 2014

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Müjde Allı, a **MSc** student of Fatih University **Institute of Biomedical Engineering** student ID **520112005**, successfully defended the **thesis** entitled "**ANALYZING EMG SIGNAL OF JAW MUSCLES BY USING EMD AND SVD TO DETECT THE EFFECT OF MISSING TEETH ON CHEWING PERFORMANCE**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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It is approved that this thesis has been written in compliance with the formatting rules laid down by the Institute of Biomedical Engineering.

Prof. Dr. Sadık KARA
Director

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Date of Defense : 2 June 2014

To my worthy parents,

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June 2014 Müjde ALLI

(Any Profession)

TABLE OF CONTENTS

Page

LIST OF SYMBOLS

Hz	Hertz
μ	Micro
p	Probability
σ	Singular value
$\sum$	Sum

ABBREVIATIONS

CHOL : Cholesterol
BMI : Body Mass Index
DWT : Discrete Wavelet Transform
EMG : Electromyography
EMD : Empirical Mode Decomposition
FPG : Fasting Plasma Glucose
GI : Gastrointestinal
HB : Hemoglobin
IMF : Intrinsic Mode Function
KLT : Karhunen-Loève Transformation
MANOVA: Multivariate Analysis of Variance
PCA : Principal Component Analysis
SBP : Systolic Blood Pressures
SNR : Signal-to-Noise Ratio
SVD : Singular Value Decomposition

LIST OF FIGURES

Page

LIST OF TABLES

SUMMARY

ANALYZING EMG SIGNAL OF JAW MUSCLES BY USING EMD AND SVD TO DETECT THE EFFECT OF MISSING TEETH ON CHEWING PERFORMANCE

Müjde ALLI

Biomedical Engineering Programme

MSc Thesis

Advisor: Prof. Dr. Sadık KARA

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The purpose of this study was to search for a correlation between extracted features from electromyography (EMG) signals of subjects and the number of their missing teeth. The correlation would show how missing teeth affect chewing performance. For this purpose, EMG signals were recorded for 10–14 seconds from patients with different numbers of teeth. The EMG signals were obtained from the right masseter, right temporalis, left masseter, and left temporalis muscles while the subjects were chewing a test material. Empirical mode decomposition (EMD) was used to decompose the signals into six subbands (IMFs). Then by singular value decomposition, each subband was reduced into five singular values. In total, one EMG recording was reduced into 30 numerical values, and those were the features to use in the analysis.

In order to do statistical analysis, subjects were split into six groups based on the numbers of their missing teeth. The groups ranged from full dentate group to group with eight or more missing teeth. The percentage of each singular value within the IMF it belongs to and the percentage of each IMF within the whole signal were examined. The mean values of groups were calculated for comparison of groups. It was observed that there is a correlation between the change of those percentages and the number of missing teeth in groups. The results of the study indicate that chewing efficiency deteriorates with the increase of the number of missing teeth.

Keywords: Teeth missing, empirical mode decomposition, singular value decomposition, mastication efficiency, jaw mucsles performance.

ÖZET

DİŞ KAYBININ ÇİĞNEME PERFORMANSI ÜZERİNDEKİ ETKİSİNİ SAPTAMAK İÇİN ÇENE KASLARINDAN ALINAN EMG SİNYALLERİNİN EMD VE SVD KULLANILARAK ANALİZ EDİLMESİ

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Bu çalışmanın amacı hastaların eksik diş sayısıyla çene kaslarından alınan EMG sinyallerinin özellikleri arasında bir kolerasyon bulmaktır. Bulunan bu kolerasyon diş eksikliğinin çiğneme performansı üzerindeki etkisini gösterecektir. Bu amaçla, farklı diş sayısına sahip hastalardan 10-14 saniye boyunca EMG sinyallerinin kaydı alınmıştır. Bu EMG sinyalleri sağ masseter, sağ temporalis, sol masseter ve sol temporalis kaslarından alınmıştır. Sinyal kaydı sırasında hastalara sakız çiğnettirilmiştir. Daha sonra EMD ile kaydedilen sinyaller altı alt-banda (IMFlere) ayrıştırılmıştır. Elde edilen her bir alt-band SVD yöntemiyle beş singular değerine indirgenmiştir. Sonuç olarak kaydedilen EMG sinyalleri 30 sayısal değere indirgenmiştir. Bu sayısal değerler sinyallerin özellikleri olarak kullanılmıştır.

Analizlerin yapılması için hastalar eksik diş sayılarına göre altı gruba ayrılmıştır. Bu gruplar tam dişlilerden sekiz veya daha fazla sayıda diş eksikliği olan hastalara kadar değişmektedir. Analizler için iki farklı hesap yapılmıştır. Bir IMF içindeki singular değerlerinin o IMF içerisideki yüzdelikleri hesaplanmıştır. Ayrıca IMF'lerin tüm data içerisindeki yüzdelikleri hesaplanmıştır. Gruplar arasındaki farklılıkları görmek amacıyla her grubun ortalama değerleri alınmıştır. Bu hesaplanan yüzdelikler ile grupların diş eksikliği sayısı arasında bir korelasyon olduğu görülmüştür. Bu çalışmanın sonuçları diş eksikliğindeki artışın çiğneme üzerindeki olumsuz etkisini gözler önüne sürmüştür.

Anahtar kelimeler: diş kaybı, ampirik kip ayrıştırma, tekil değer ayrıştırma, çiğneme verimliliği, çene kasları performansı.

CHAPTER 1

INTRODUCTION

The human health is partially dependent on nutritional habits. The increased number of unreplaced teeth causes restriction in diet, and this restriction increases the risk of developing chronic diseases[1, 2]. In several studies, the number of teeth is associated with cardiovascular mortality[3-5]. Additionally, even mental health problems may have an association with unreplaced teeth[6].

Teeth missing is an inevitable case for most people in different stages of their life. The decrease in the number of teeth may affect the health of humans in many aspects. People with nine or more unreplaced teeth have a lower masticatory efficiency[7]. Several digestive troubles appear as a result of insufficient masticatory function[8], because the mastication is the first stage of the digestive system[9]. It has been hypothesized that the number of missing teeth is related to physiologic variables, such as systolic blood pressures (SBP), hemoglobin (HB), fasting plasma glucose (FPG), total cholesterol (CHOL), and body mass index (BMI)[10]. Furthermore, an association of diabetes and hypertension with tooth loss has been found[11].

Although both age and number of missing teeth have negative effects on the mastication process, it is stated that the effect of dental status on chewing efficiency is more than the effect of age per se[12-14].

1.1 Literature Survey

In the literature, mostly, some basic calculations were done on raw electromyography (EMG) signals, or some interviews were done to patients by using questionnaires for determining the chewing performance with remaining teeth. In [15], the discrete wavelet transform (DWT) method was applied to EMG data for observing the performance decrease of jaw muscles with the decrease of the number of teeth within two groups. They displayed the obvious difference between the two groups in the signal features by analyzing the coefficients obtained from DWT.

Empirical Mode Decomposition (EMD) was proposed as a technique for processing nonlinear and nonstationary signals[16]. This method was used in different areas for signal processing, such as electromagnetic field time series analysis[17], fluid dynamics, ocean engineering[18], and financial applications[19].

Biosignals are an example of nonlinear and nonstationary signals. Several previous studies implemented the application of EMD on biological signal processes, such as analysis of respiratory mechanomyographic signals[20], ECG enhancement artifact and baseline wander correction[21], crackle sound analysis in lung sounds[22], heart rate variability[23], R-peak detection[24], and enhancement of cardiotocograph signals[25]. In the diagnosis of atherosclerosis, EMD was used for the signal analysis of Doppler ultrasound sonogram[26].

Singular Value Decomposition (SVD) was first introduced in 1980 [27] with its applications in linear algebra and linear systems. In 1986 [28], proposed SVD as a part of the singular spectrum analysis. SVD is closely related with the Karhunen-Loève transformation (KLT) [29] or principal component analysis (PCA) [30] in signal processing. The relationships among SVD, PCA, and KLT are discussed and explained in [31].

It has been used as a useful tool for signal processing. In several studies, SVD has been used to decontaminate the signal from noise [30, 32-35]. It is introduced as a very robust technique which satisfies high-resolution discrimination against noise contamination[36]. Recent studies show examples of the application of SVD on biosignals[37, 38].

1.2 Purpose of the Thesis

This study aims to do a more detailed investigation to exhibit the correlation between chewing efficiency and dental status with a wide range of patient groups. This study consists of applying EMD to EMG records followed by applying SVD. After that, some statistical clues on the physiological changes in the jaw muscles are investigated according to the number of absent teeth.

1.3 Arrangement of Thesis

In this article, the correlation between teeth missing and the parameters extracted from the EMG signals of jaw muscles is investigated. The organization of the paper is such that;

Chapter 2 provides the theoretical backgrounds about importance of digestion, EMD, SVD, and EMG signal.. In chapter 2, the materials and data acquisition are described. The steps of the process applied to EMG data are explained, and the results are given in Chapter 4. In Chapter 5, the discussion and conclusion about this study are discussed.

CHAPTER 2

BACKGROUND

This section contains general information about digestive system, EMG, EMD, and SVD. The vital importance of digestive system and the importance of oral health in digestive system are emphasized.

2.1 Digestive System

Digestive system has a vital importance for our life. This inconceivable system breaks down food into nutrients like carbohydrates, protein, fats, and vitamins which are appropriate for usage of body cells. After food changed into smaller molecules of nutrients by digestive system, the blood absorbs them and carries to cells throughout the body. Those nutritients are used for energy, growth, and repair of body.

During digestion, food moves through the Gastrointestinal (GI) tract. GI tract consists of mouth, esophagus, stomach, small intestine, and large intestine. It ends up with anus. Digestion begins in the mouth with chewing and swallowing food. In the mouth, food is devided into small pieces and it is mixed with saliva which helps to digestion of starches. After that, as food passes through the GI tract, it mixes with other digestive juices which cause large molecules of food to break down into smaller molecules. These small molecules are absorbed by walls of small intestine and into bloodstream. Then, they mix with blood and are carried to the rest of the body. Waste products of digestion pass through the large intestine and eventually they are throw out of the body. Table 2.1 summarizes the organs participate in digestion and their funtions.

Table 2.1 The digestive process [39]

Organ	**Movement**	**Digestive Juices Used**	**Food Particles Broken Down**
Mouth	Chewing	Saliva	Starches
Esophagus	Swallowing	None	None
Stomach	Upper muscle in stomach relaxes to let food enter and lower muscle mixes food with digestive juice	Stomach acid	Protein
Small intestine	Peristalsis	Small intestine digestive juice	Starches, protein, and carbohydrates
Pancreas	None	Pancreatic juice	Starches, fats, and protein
Liver	None	Bile acids	Fats

2.1.1 Gastrointestinal Tract

Gastrointestinal tract is known as two part, upper GI tract and lower GI tract. The upper GI tract includes mouth, esophagus, and stomach while the lower GI tract begins at small intestine and finishes with large intestine. During degistion, food moves through the IG tract by muscle moves of walls of GI tract organs. This movement of organ walls is called peristalsis.

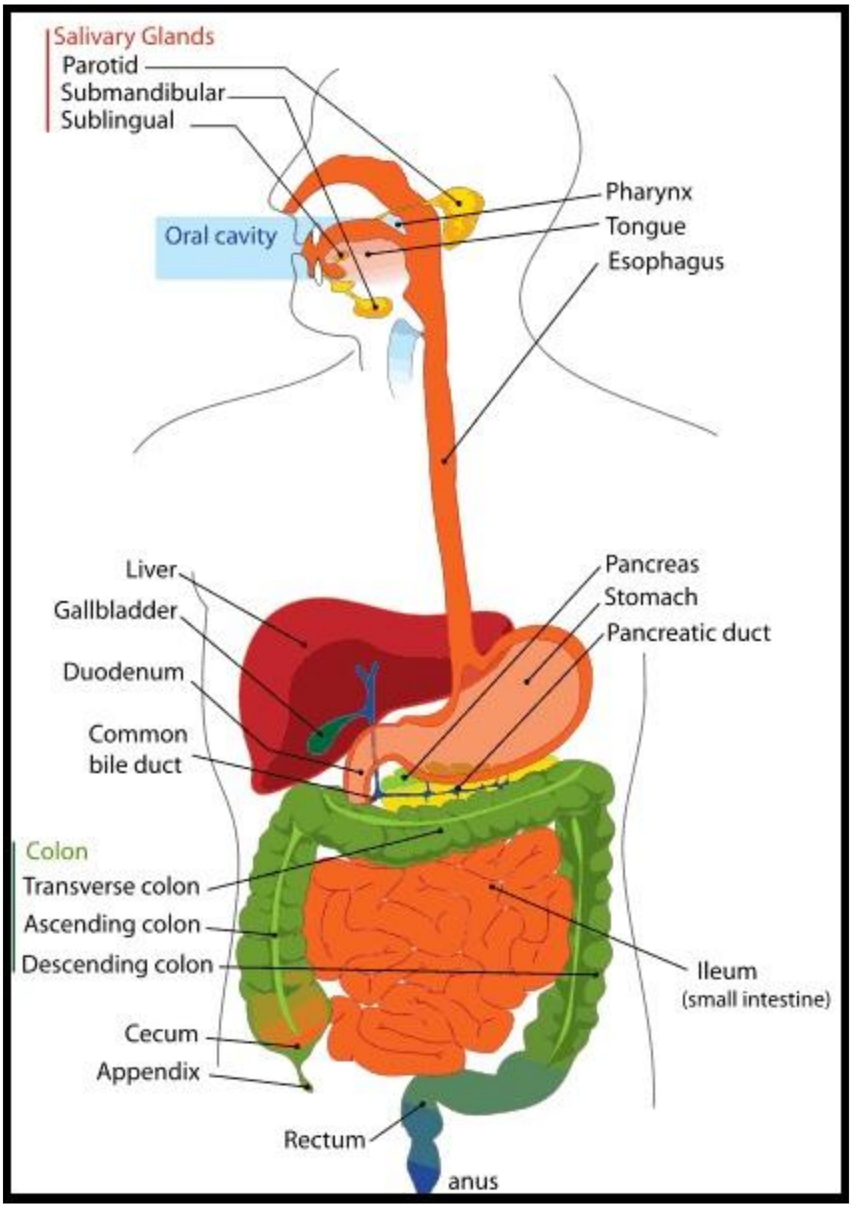


Figure 2.1 Digestive system [40]

2.1.1.1 Mouth

Digestion begins in mouth in which chewing is performed. Chewing is a mechanical process that devides food into smaller pieces in order to have wider surface of food for enzymatic degistion. Muscles of tongue and cheek, upper and lower jaw, and teeth serves in chewing (mastication) process. During mastication, saliva is excreted by exocrine glands in oral cavity and it helps to form bolus. There are some enzymes in saliva which begin chemical decomposition of starches in mouth. After chewing is done, bolus is swallowed by help of touch receptors in the pharynx.

2.1.1.2 Esophagus

The esophagus is muscular tube that carries food from the pharynx to the stomach. The muscles of esophagus move the swallowed bolus to reach the stomach. This moves are involuntary and proceed under the control of the esophagus and brain.

2.1.1.3 Stomach

The stomach is located below the diaphragm and above the small intestine. It stores swallowed food and mixes the food with digestive juice which it produces. The swallowed bolus coming from the esophagus is entered into stomach by relaxation of the muscle of the upper part of the stomach. The muscle of the lower part of the stomach serves to mix the food with digestive juice. After its task done, the stomach empties its content into small intestine in small amounts.

2.1.1.4 Small intestine

The most of digestion takes place in the small intestine in which the pancreas, liver, and intestine digestive juices performs their action. The muscles of the small intestine mix food with all of those digestive juices and push the mixture forward for the rest of digestion. Additionally, the walls of the small intestine absorb the digested nutrients into the bloodstream in order to be carried to the rest of body by blood.

2.1.1.5 Large intestine

The large intestine is the last part of the digestive system. It is also called as colon which is the name of the longest component of large intestine. The large intestine absorbs the remaining water and any remaining nutrients from waste product of degistion which mostly includes undigested parts of food and played out cells. Eventually, the large intestine changes the waste from liquid into stool and stool is pushed out of the body by the rectum.

2.1.2 Importance of Mastication on Digestion

Digestion process begins in the mouth, also called theoral cavity. By the organs in the mouth- teeth, tongue, and saliva glands- food is mechanically and also chemically digested with masication process. By mechanical digestion, the large aggregates of food are broken down into smaller pieces in order to have increased surface area for digestion in the stomach and intestines. Beside that, complex carbohydrates are splitted into simple carbohydrates by saliva in the mouth as cemical digestion. Mastication also causes to send signal to the rest of gastrointestinal system in order them to be triggered for the digestion process

Digestion requires a great energy especially for food which are improperly chewed. In the case of a proper chewing, the stomach works more efficiently and breaks down food faster while it is easier for intestines to absorb nutrients as they pass through. Additionally, food is exposed to saliva for a longer period of time in the case of a proper chewing. This is important for digestion because it makes easier tor food to pass through the esophagus and also enzymes in saliva contribute to the chemical process of digestion. By the chemical digestion in the mouth, starches are broken down into simple sugars and the first stage of fat is also occurs in the mouth.

The pylorus which is the muscle at the lower end of stomach has to relax to allow food to pass from stomach into small intestine. This relaxation is more easier and efficient by the help of sufficient saliva from proper chewing. On the other hand, when large particles of improperly chewed food enter stomach, they may pass to small intestine undigested. In this case, bacteria in the intestines will try to break down them or those undigested particles will start to putrefy. This condition may lead to some digestive problems such as abdominal pain, cramping, bloating, gas, diarrhea or constipation.

On account of all those negative impacts of improper mastication, mastication has a profound importance on digestion process [41].

2.1.2.1 Teeth

The teeth are 32 small, hard structures set in the upper or lower jaw. They are made of bone-like structures which contain blood vessels and nerves. Hence, teeth are living organs which are designed for chewing food. Not all teeth have sae shape. Their shapes are related to their functions. Some teeth tears food and some mashes food. Moreover, teeth also give shape to the face and help to speak clearly.

2.2 Edentation

Edentation is the term used in medical for missing teeth. It can be single tooth missing, several teeth missing or even all teeth missing. There are many causes of teeth missing as well as many cosequences.

2.2.1 Causes of Edentation

- Congenital absence
- Genetics and age
- Poor oral hygiene
- Periodontal diseases
- Diabetes and stress
- Hormonal changes
- Some medications
- Poor nutrition
- Trauma and bruxism
- Smoking and drinking alcohol
- Not treating caries and not replacing lost teeth [42, 43]

2.2.2 Consequences of Edentation

- Decrease in chewing performance and efficiency
- Limitation of food choices
- Poor nutrition based on limitations
- Shift and inclination of remaining teeth
- Change in face appearance based on shift of remaining teeth
- Impair in speaking ability
- Social embarrassment
- Weakening of other teeth and their possible loss
- Jaw problems [42, 43]

2.3 Electromyography

The electromyography (EMG) signal is a biosignal that detects the electrical activity of nerve and muscle cells. The waveform of those electrical activity recordings is called electromyogram. Beside that there are three types of muscles in human body (skeletal muscle, smooth muscle, and cardiac muscle), only skeletal muscles are studied with the application of EMG [44]. EMG helps in diagnosis of muscle abnormalities such as weakness, numbness, tingling sensation, neuro-muscle junction problems, or nerve damages. Moreover, it can measure the muscle strength, sensory and motor conduction velocities. In short, EMG measurement gives wide information about the condition of muscles and nerve.

Skeletal muscles control all voluntary movements. They contain nervous, blood vessels, connective tissues and mostly muscle tissues. Muscle tissue consists of nearly parallel cells and the muscle fibers. Muscle fibers are activated by the central nervous system by electrical signals calling action potentials. Those electrical signals are transmitted by motor-neurons. The contraction of skeletal muscle is a consequence of action potentials at the muscle fiber membrane. The EMG signal is based upon this process which is initiated from motor neurons.

The electromyogram measurement might be invasive or non-invasive. Invasive measurement is done by applying the conductive elements (needle electrodes) within the muscle. On the other hand, non-invasive measurement is performed by applying electrodes (surface electrodes) to the skin surface. Needle electrodes are very thin (diameter of 50μ or less) wires made of silver, platinum or stainless steel. They are inserted into the muscle. The insertions of needle electrode in tissues may cause tissue damage due to movement of electrode. Needle electrodes can be monopolar consisting of one wire or bipolar consisting of two wires. They are used for diagnostic record or deep-small muscles or deep-small nerves.

Surface electrodes are usually made of silver-silver chloride. They are more commonly used because of their advantages. First of all, using surface electrodes is a non-invasive method with minimal risk for subjects. It is easy to adhere the surface electrodes to the skin and to detect the muscle activities. The measurement done by surface electrodes is called Surface EMG (sEMG) which measures muscle electrical activity that occurs during muscle contraction and relaxation. sEMG signals are used widely for diagnosis and to decide the treatment of some neuropathic, myopathic and neuromuscular junction diseases [45].

The EMG signal is first picked up by electrode and amplified because the signal has extremely small voltage values. Additionaly, it must be processed to eliminate high and low frequency noises causing from body inside or outside artifacts. This process contains many implification and filtration stages.

EMG quality is described by signal-to-noise ratio (SNR) which means the ratio between the measured EMG signal and noise contributions from inside or outside of body. SNR is wanted to be as high as possible. In order to minimize noise contamination there should be a balance of impedance between electrode sites during the measurement period. At least, they should be close to each other. The stability in impedance over time and the balance in impedance between electrode sites have a profound effect on the SNR of EMG signal [46]. Beside that, properties of electrodes, amplifiers, analog to digital converter, storage element, and electrode-skin interaction are some other parameters to effect reliability of measured EMG signal.

2.4 Empirical Mode Decomposition

EMD is one of recently developed and efficient decomposition technique for composite, nonlinear, and non-stationary signals. It is firstly published by Huang [16]. EMD is a data-driven and adaptive method that does not require any known basis function. It decomposes a complex signal into well defined instantaneous frequency components, which are called as intrinsic mode functions (IMFs), plus a residue according to different frequency bands. Intrinsic mode functions are orthogonal, local, and adaptive decompositon which perpesent the characteristic time scale and save the phisical properties of the signal. EMD is highly efficient in nonlinear and non-stationary signal because its IMFs are not predetermined, they are basis functions which are detemined by the signal itself.

Unlike Wavelet decomposition and Fourier decomposition, EMD does not use a priori basis in order to docompose the signal. Because the basis of EMD is produced depending to the signal, the decomposition is based on the local time scales of data. Thus, EMD decomposes time series from nonlinear and nonstationary signals in the time domain successfully. It has high decomposition, efficient time and frequency localization on nonlinear and nonstationary data series [16].

The application of EMD results a set of IMFs plus a residual signal. The components are extracted from original signal by an iterative and shifting process called "sifting". Those extracted components are required to have some certain properties to be characterized as intrinsic mode function. An IMF is defined by two criterians those are predetermined by [16];

1. It should have equal number of extrema (local maxima and minima) and zore crossings, or at most differ by one.

2. Its upper envelope and lower envelope which are defined by local maxima and minima should be symetric with recpect to zero at any point. This condition implies that the mean of envelops is zero at any point.

As already implied, IMFs are obtained by a process called sifting. Sifting process for signal $\mathrm{s(t)}$ can be summarized into 4 steps;

1. Identify all local extrema (all local maxima and minima)
2. Form the the upper and lower envelopes $\mathrm{e_{up}(t)}$, $\mathrm{e_{low}(t)}$ of signal $\mathrm{s(t)}$ by connecting all local maxima and local minima with cubic spline curve.
3. Compute the mean of envelopes.

$$m(t) = \frac{\mathrm{e_{up}(t)+e_{low}(t)}}{2} \tag{2.1}$$

4. Obtain proto-IMF $d(t)$ by extracting mean from the signal.

$$d(t) = s(t) - m(t) \tag{2.2}$$

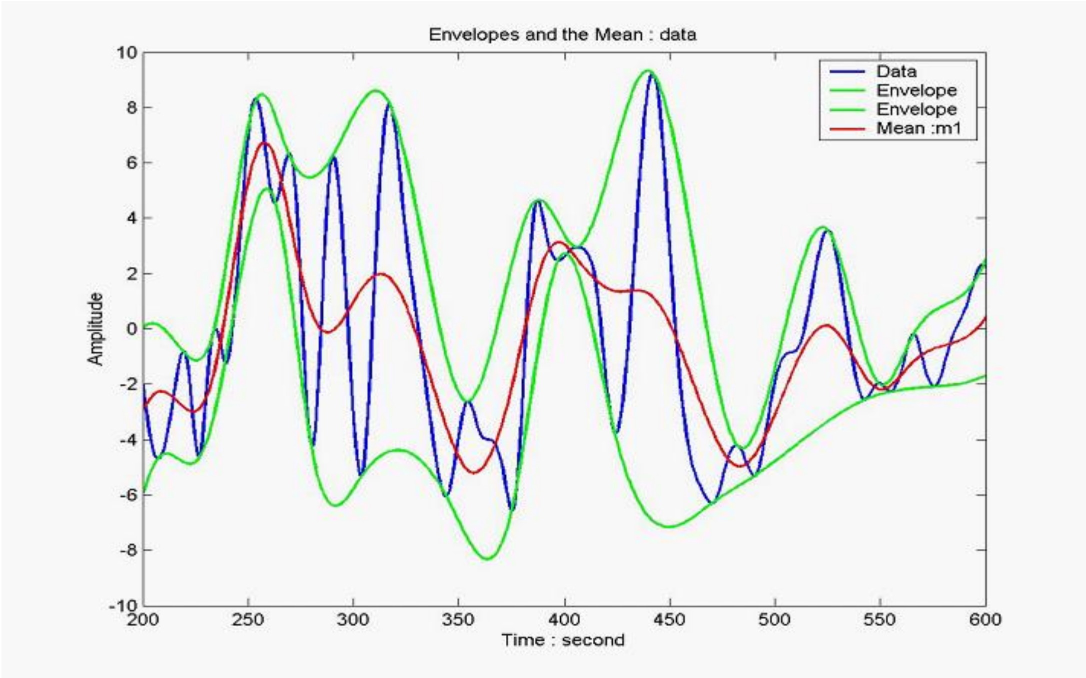


Figure 2.2 Envelops and mean [47]

5. Check if $d(t)$ satisfy the criterians of IMF. If it does, it is an IMF.
6. If $d(t)$ does not satisfy the criterians of IMF, regard $\mathrm{d(t)}$ as new $\mathrm{s(t)}$.Then repeat step 1 to 4 until $\mathrm{d(t)}$ satisfy the IMF criterians. Eventually, IMF1(t) is obtained.
7. After obtaining $IMF1(t)$, compute residual $r(t)$ by extracting $IMF1(t)$ from the signal and regard $r(t)$ as new signal. Then repeat step 1 to 6 in order to obtain next IMF.

$$r(t) = s(t) - IMF_1(t) \tag{2.3}$$

In order to terminate this sifting process, several different stoppage criteria can be used [16, 48, 49]. In our study, we use the method which is determined in [48] as stoppage criteria for calculation of IMFs. In the end of this process, the signal will be docomposed as;

$$s(t) = \sum_{i=1}^{N} IMF(i) + r_N(t) \tag{2.4}$$

Thus, the signal is decomposed into N IMFs and a residual signal by the application of EMD. The first IMFs represent the fast oscillation modes while the last IMFs represent the slow oscillation modes.

2.5 Singular Value Decomposition

SVD is a way to turn data into information [50]. It is a powerful method of matrix analysis based on a theorem from linear algebra which get useful data from information containing within a matrix. It can expose a lot of properties of the original data matrix and indicate where the information is concentrated [51]. The SVD of a matrix is more robust than the original matrix to numerical errors in computations.

Singular Value Decomposition states that a matrix $A_{m \times n}$ can be decomposed into 3 matrices [52, 53];

$$A_{m\times n} = U_{m\times m} S_{m\times n} V^T_{n\times n} \tag{2.5}$$

$$A_{m\times n} = U^T \times U = I \tag{2.6}$$

$$A_{m\times n} = V^T \times V = I \tag{2.7}$$

Here, U is a orthogonal matrix that contains orthonormal eigenvectors of AA^T as its columns. The columns of U are called as left-singular vectors of A. V is an orthogonal matrix that contains orthonormal eigen vectors of $A^T A$ as its columns. The columns of V are called right-singular vectors of A. Lastly, S is a diagonal matrix that contains the normalized singular values form U or V as its diagonal entries [54]. I is obviously unit matrix.

$$S = diag[\sigma_1(A), \dots., \sigma_n(A)] \tag{2.8}$$

The diagonal entries of S, $\sigma_i(i = 1, \dots n)$ are the normalized singular values of A which are the square roots of nonzero eigenvalues of both AA^T and $A^T A$. Only the $(i,i)^{th}$ entries of S can be nonzero, others are zero. They are in descending order along the diagonal. If the rank of A is k, then;

$$\sigma_1 \geq \sigma_2 \dots . \geq \sigma_k \tag{2.9}$$

$$\sigma_{k+1} = \sigma_{k+2} \dots . = \sigma_n = 0 \tag{2.10}$$

If we write $U = (u_1, \dots u_m)$ and $V = (v_1, \dots v_n)$, we can write matrix A as;

$$A = \sum_{i=1}^{k} \sigma_i u_i \, v_i^T \qquad (2.11)$$

The vital part of the results singular values obtained from S diagonal matrix.

CHAPTER 3

MATERIALS AND METHODS

In this section, general information about the subjects and materials which are used in recent study is given. Additionally, the the procedure of data acqusition and signal examination are explained, too.

3.1 Subjects

In total, 69 patients participated in this study. Those were the patients treated at the Faculty of Dentistry of Erciyes University, Turkey. The demographic information about the patients is given in Table 3.1. The subjects may have had different numbers of missing teeth on the right side but not on the left side, on the left side but not on the right side, on neither side, or on both sides. They had visited the hospital for medical care for their oral and dental health and volunteered to participate in this study. All of the participants were informed about the aim and methodology of the study. The distribution of patients through the number of missing teeth is provided in Figure 3.1 (for right side) and Figure 3.2 (for left side).

Table 3.1 Demographic information about patients.

Patients	**Minimum Age**	**Maximum Age**	**Average Age**
Men	22	45	36.5
Women	24	48	39.1
Total	22	48	37.3

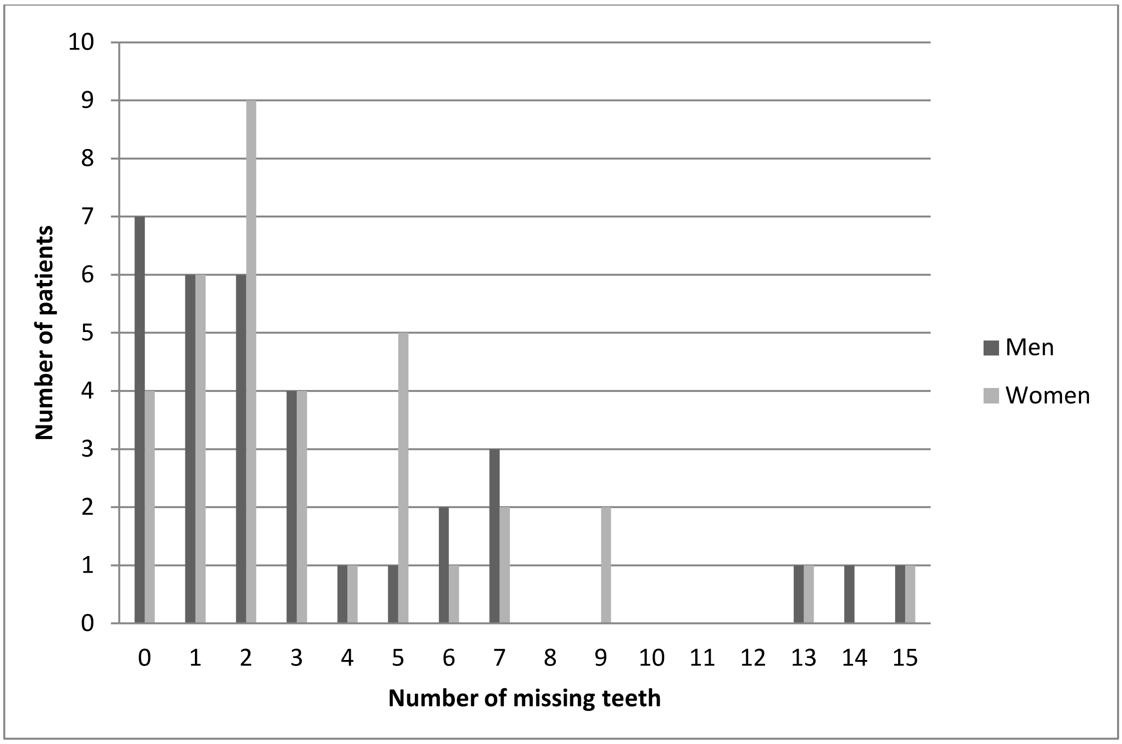


Figure 3.1 Distribution of patients for the number of missing teeth on the right side.

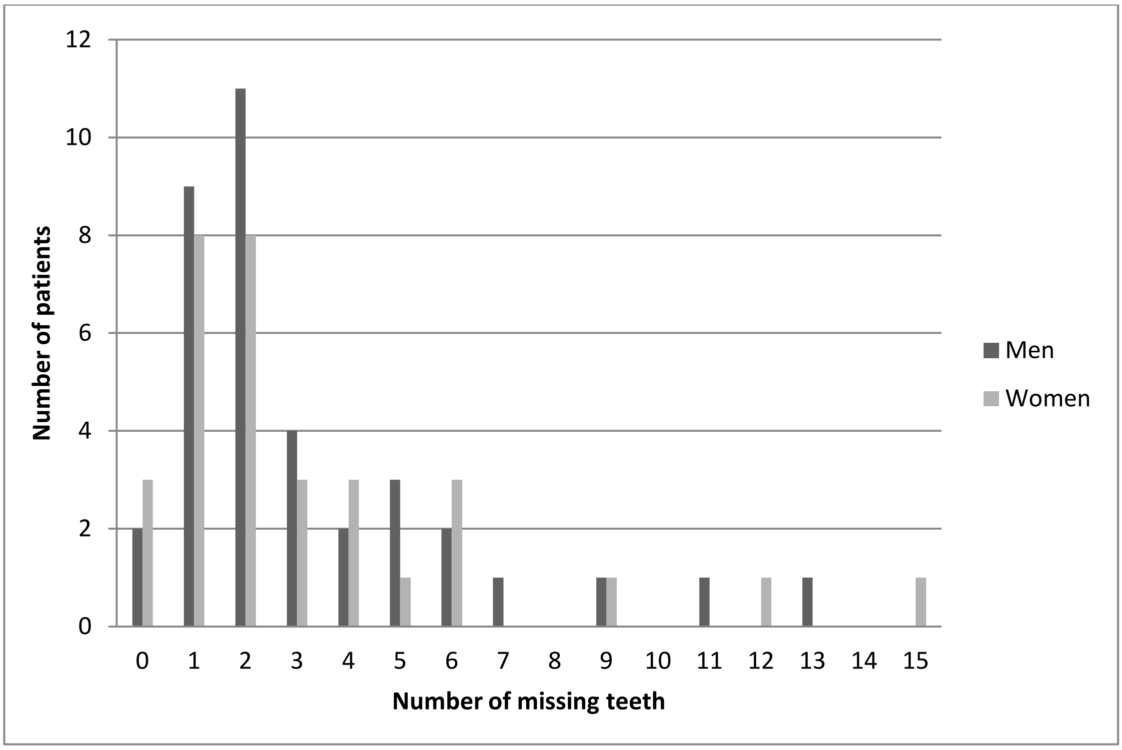


Figure 3.2 Distribution of patients for the number of missing teeth on the left side.

3.2 Materials

EMG signal recording was done by a Biopac (model MP150, BIOPAC Systems Inc., Goleta, California, USA) data acquisition system in the Faculty of Dentistry at Erciyes University. The high-pass filter of Biopac data acqusition system was set to 1.0 Hz and low-pass filter was set to 500 Hz [9]. The EMG signals were amplified with a gain of 5000 (EMG100C amplifier) and the serial output of EMG recorder device unit was sampled at 5000 samples/second [4]. Then the EMG recordings were sent to a personal computer through an input/output card. For storage and analysis of EMG data, a personal computer was used. In total, the system hardware consists of a MP150 EMG recorder, an input/output card, and a personal computer. All applications to EMG data and analysis were done by a MATLAB software tool (MATLAB 7.6.0, R2008a, MathWorks Inc., Natick, Massachusetts, USA).

The distance between electrodes was 20 mm; hence, the recommended interelectrode distance for bipolar recording is 20 mm [55]. EMG signals for each patient were recorded from the masseter and temporalis muscles, which are responsible for the chewing process. First, the skin over the muscles was cleaned with alcohol and dried. Then the electrodes were filled with an electrode gel and attached to the skin of the patient with adhesive washers for stability of impedance. The electrodes had a 4 mm recording diameter. Common ground electrodes were attached to the earlobe of the subject. Two of the active electrodes were placed on the temporalis, and two of them on masseter muscles, as shown in Figure 3.3. They were attached to each other by a medicated plaster. The EMG recording was done separately for the right and left sides. For each side, the active electrodes were attached to the muscles of that side, and chewing was done on that side.

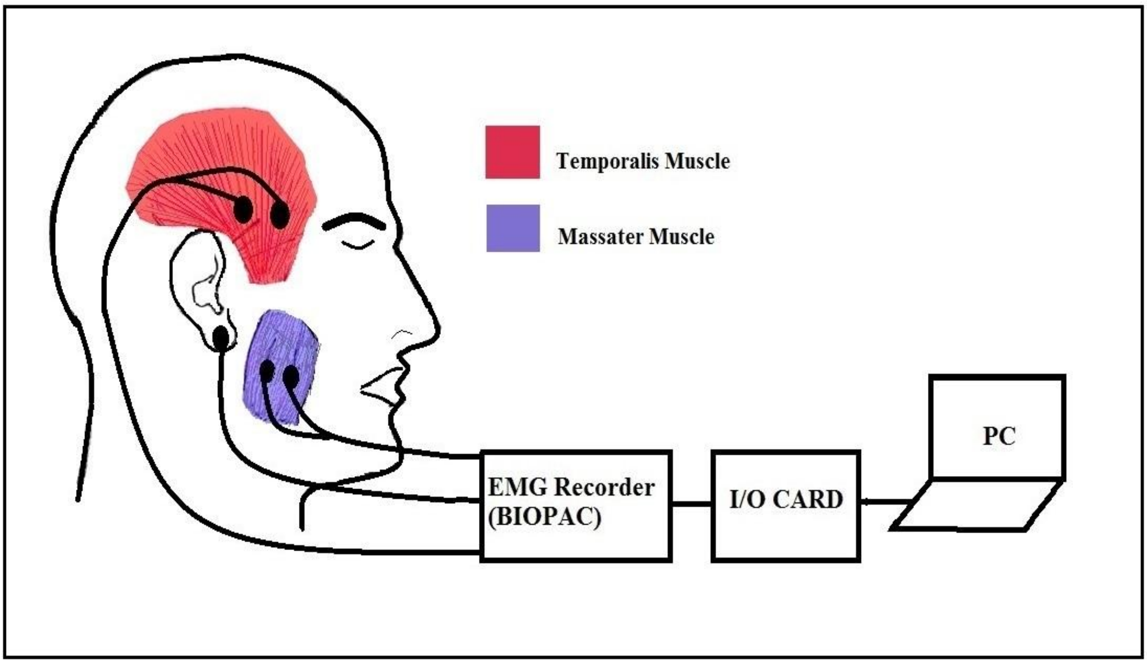


Figure 3.3 EMG data equisition from jaw muscles by BIOPAC system.

EMG recordings of chewing were made while the subjects were sitting upright in a dental chair. The environment was purged from magnetic pollution. Chewing gum was used as test material. It satisfies reliability for testing masticatory efficiency with its uniform properties. The study subjects chewed gum three times for 10–14 seconds.

The acquired EMG data was composed of five channels, as shown in Figure 3.4. From up to down, they were masticatory right, masticatory left, temporary right, temporary left, and the reference channel. Intermittent burst appears in the signal, which corresponds to cycles of chewing. Because this is a right-side chewing, it is obviously seen that the signal of right-side muscles has a higher pick-to-pick value. Nevertheless, a similar pattern appears on the left-side muscles' activity.

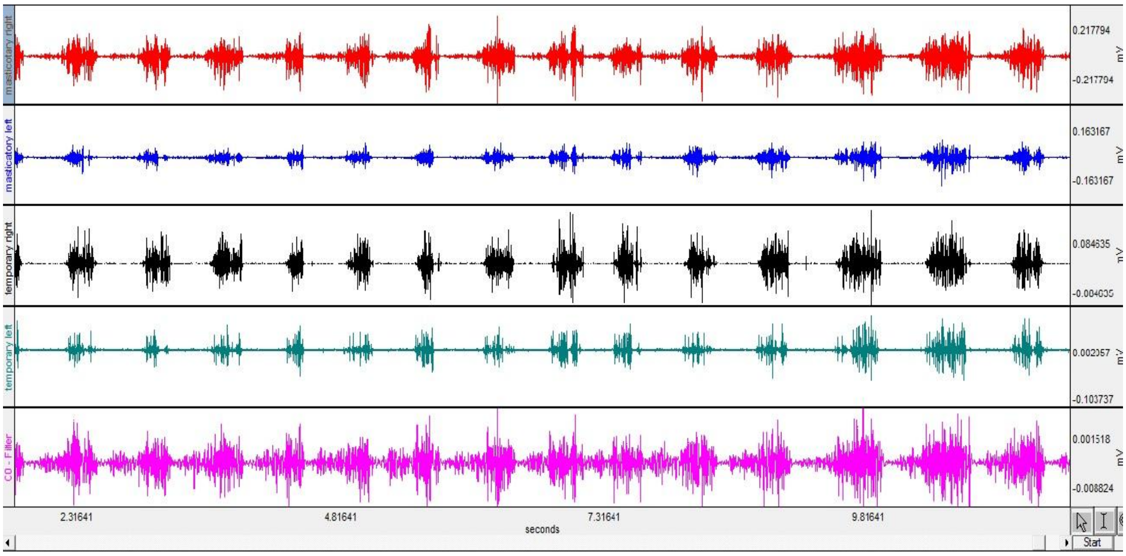


Figure 3.4 Raw EMG data of chewing activity (on right side).

3.3 Methods

The summary of the process done in this study is shown in Figure 3.5. The preprocessing part is making EMG data suitable for MATLAB applications through a personal computer. EMD is for decomposing the signal into its IMF. SVD is for getting the singular values of each IMF. Lastly, the statistical analysis is for finding out the relation between features of EMG and the number of teeth of a patient.

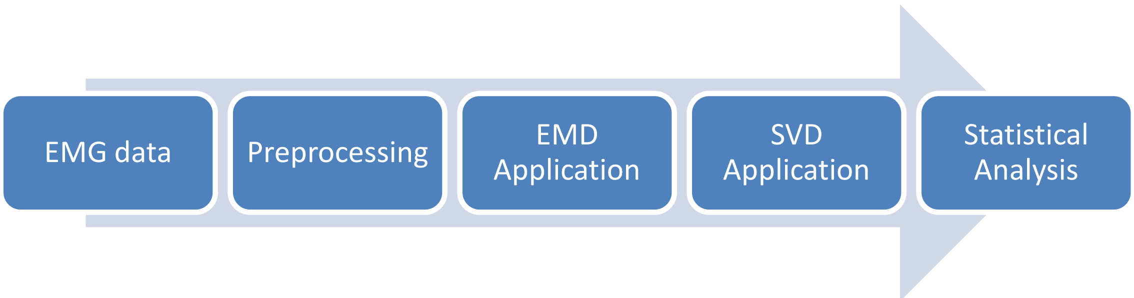


Figure 3.5 Flow chart of applications on EMG data.

3.3.1 Preprocessing

The EMGs were used to see if there is any feature in the chewing patterns that correlates with the number of missing teeth. For this purpose, firstly, a preprocessing was done during and after data acqusition; the EMG signals were amplified with a gain of 5000 and the serial output of the EMG recorder device unit was sampled at 5000 samples/s. The recording files which were in form of ".acq" were converted to ".mat" format for MATLAB applications.

3.3.2 EMD and SVD applications

With the help of the MATLAB program, empirical mode decomposition was applied to all EMG data. This application divides the EMG signal into well-defined instantaneous frequencies. At the end of this process, a total of six IMF values were obtained, and those became the input of singular value decomposition. SVD algorithm was applied to those subbands' EMG signal in order to separate the interesting signals from noisy signals. SVD produced five singular values for each IMF. In total, we ended up with 30 numerical values for each EMG recording.

3.3.3 Statistical Analysis

As the aim of this study was to discover the connection of teeth missing to EMG features, a statistical examination was required on singular values. At the beginning of the statistical analysis, grouping of patients' data was made. Their EMG data were partitioned into six groups according to the number missing teeth as listed in Table 3.2. This grouping was done to gather data on the right and left sides separately.

Table 3.2 Groups of subjects based on the number of their missing teeth.

Group No	Group Definition
I	Healthy subjects
II	Subjects with 1 missing tooth
III	Subjects with 2 missing teeth
IV	Subjects with 3 or 4 missing teeth
V	Subjects with 5,6 or 7 missing teeth
VI	Subjects with 8 or more missing teeth

In order to examine the singular values, the percentage of each singular value was calculated within its own IMF, and it was calculated for all singular values of all IMFs separately. For example, the percentage value for first singular value of first IMF was calculated as;

$$\%IMF_1(S_1) = \frac{IMF_1(S_1)}{\sum_{n=1}^{5} IMF_1(S_n)} \times 100 \tag{3.1}$$

Same calculation was done for other singular values of first IMF, then for other IMFs too. One individual EMG data was reduced to 30 singulars. Hence, 30 percentage values were obtained for each separate data. As mentioned before, there were six groups of subjects. The average of each group was calculated to see the difference among the groups' mean values.

The second calculation in statistical analysis is the percentage of each IMF within the whole signal. For instance, the formula for calculation of the first IMF's percentage within the whole signal is;

$$\%IMF_1 = \frac{\sum_{n=1}^{5} IMF_1(S_n)}{\sum_{m=1}^{6}\sum_{n=1}^{5} IMF_m(S_n)} \times 100 \quad (3.2)$$

This calculation was done for all IMFs which compose the signal.

CHAPTER 4

RESULTS

4.1 Percentage of Singular Values within IMFs

For each IMF, first singular values are the primary one because they are in descending order. It is observed that the first singular value of IMFs is the most affected one from the change of dental situation. This change is maximum for first IMF and minimum for last IMF. Figure 4.1 shows the average percentage values of first singular values of each IMF for the patient groups. The vertical axis represents the average of percentage values of first singular values within IMFs. The horizontal axis contains the patient group numbers.

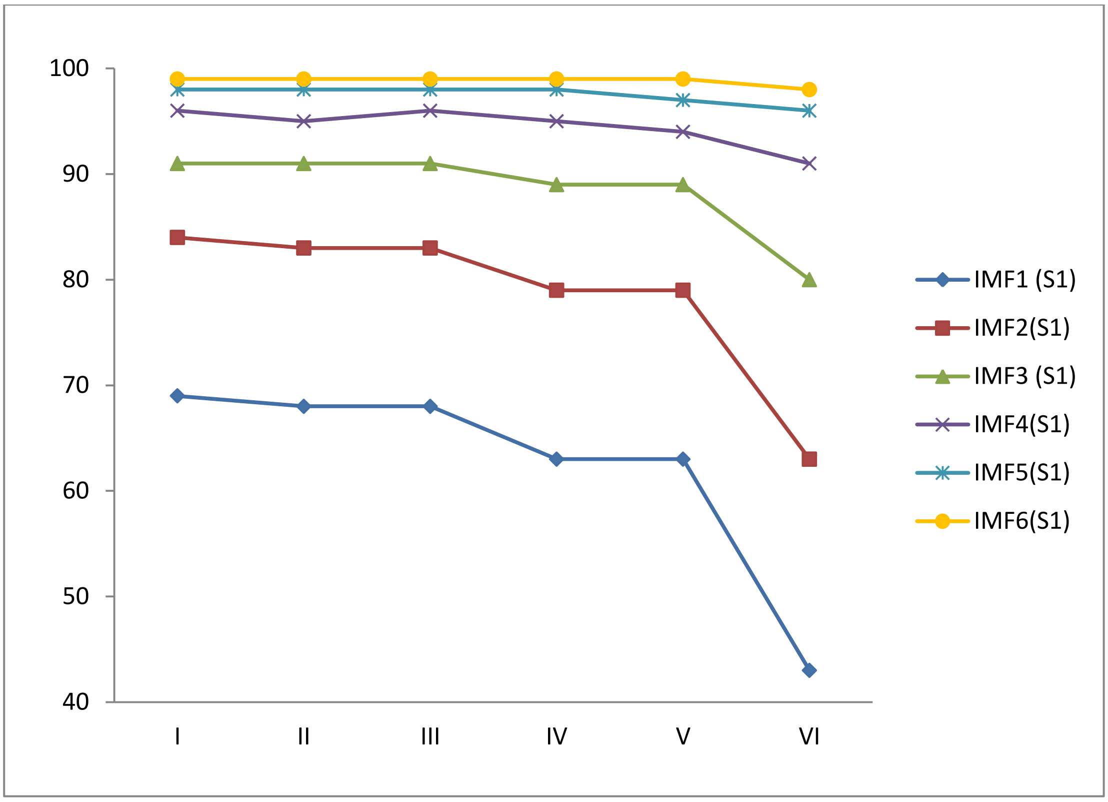


Figure 4.1 Percentage of first singular value within IMFs for right masseter muscle.

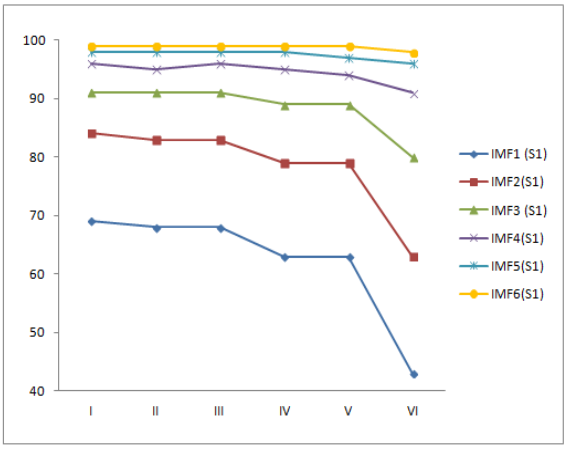
There is an obvious decrease in the percentage of top 3 IMFs' first singular values while progressing from full dentate group (Group I) toward the group that has the highest number of missing teeth (Group VI). The decrease becomes less for the last three IMFs.

The more accurate statictical information is obtained by one-way MANOVA (multivariate anaysis of variance). The pick values, mean values and obtained p-values of groups for the extracted features are listed in Table 4.1. There are 3 features of EMG data of patiens. Those are the first singular value of IMF1, first singular value of IMF2, and first singular value of IMF3. Maximum, Minimum and mean values of those features for all of groups are given. Additionally, the results of one-way MANOVA amoung all groups for three features is valid in Table 4.1.

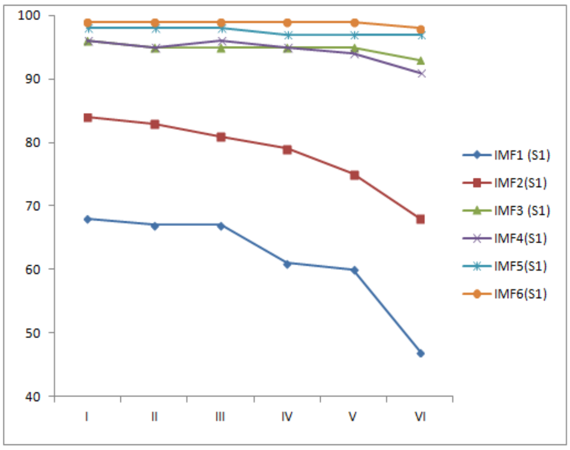
Table 4.1 Comparision of extracted features and p-values for first calculation.

		Group I	Group II	Group III	Group IV	Group V	Group VI	p values
IMF1(s1)	Min.	58.97	53.24	45.87	39.36	44.46	23.46	7.71e-011
	Max.	81.07	74.69	75.62	74.70	73.72	71.39	
	Mean	69.92	68.09	68.39	63.58	63.13	43.45	
IMF2(s1)	Min.	75.22	76.49	59.74	62.20	46.98	45.49	5.13e-009
	Max.	90.99	87.79	89.52	87.84	89.86	83.97	
	Mean	84.35	83.08	83.27	79.83	79.07	63.82	
IMF3(s1)	Min.	87.12	88.91	84.05	83.66	71.91	67.88	7.84e-011
	Max.	95.25	94.52	95.11	94.17	94.58	91.47	
	Mean	91.97	91.61	91.62	89.78	89.03	80.86	

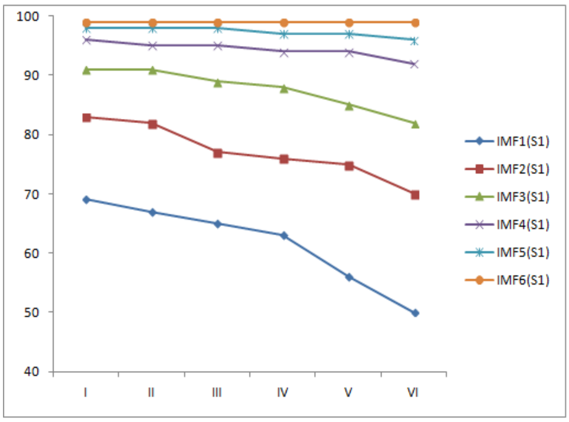
Figure 4.2 contains four separate graphs. Two of them (top row) are graphs for right-side muscles while right-side chewing is performed. The other ones (bottom row) are the graph for left-side muscles while left-side chewing is performed. Thus, Figure 4.2 allows the comparison of right and left sides for the same muscle, at the same time, the comparison of masseter muscle and temporalis muscle for the same side. It is observed that the decrease rate in the average percentage values of first singular value within IMFs is getting smaller for the left side in comparison with the right side. Similarly, this change is less for temporalis muscle in comparison with the masseter muscle on both sides.



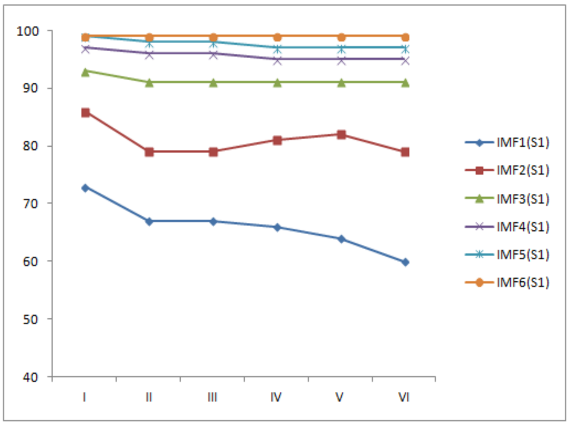
a) Percentage of first singular values within IMFs for right masseter muscle.



b) Percentage of first singular values within IMFs for right temporalis muscle.



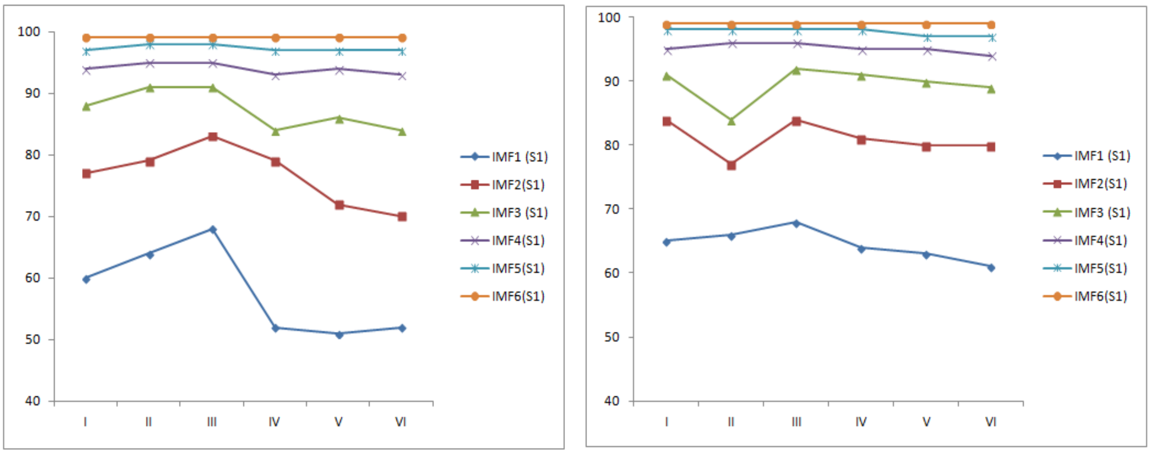
c) Percentage of first singular values within IMFs for left masseter muscle.



d) Percentage of first singular values within IMFs for left temporalis muscle.

Figure 4.2 In first statistical calculation, comparison of right-left and masseter-temporalis muscles.

The correlation between the number of missing teeth and the decrease in the percentage values, as obtained above, is not valid for the opposite muscles of the chewing side. For example, while the right-side chewing is performed, the EMG signal of the left-side muscles was supplied too. The current method was also applied to those EMG signals. However, as expected, the correlation that appeared in the right-side muscles' data does not exist for the left-side muscles' data. In Figure 4.3, the average percentage values of the first singular values for the left muscles while the right-side chewing is performed are shown.



a) Graph of left masseter muscle while right chewing.

b) Graph of left temporalis muscle while right chewing.

Figure 4.3 Graph of left mucsles during chewing on right side.

4.2 Percentage of IMFs within the whole EMG signal

In this analysis, once again, the average values were calculated within each group of subjects. This time, the results show that when the patients' number of missing teeth increases, the percentage of first and second IMFs decreases ($p < 0.05$), while the other IMFs' percentage increases, and consequently, they get closer to each other. Figure 4.4 illustrates the decrease in the percentage values of the first and second IMFs and the increase of other IMFs within the signal. In Figure 4.4, the vertical axis represents the average of percentage values of IMFs within the whole signal, and the horizontal axis contains the patient group numbers.

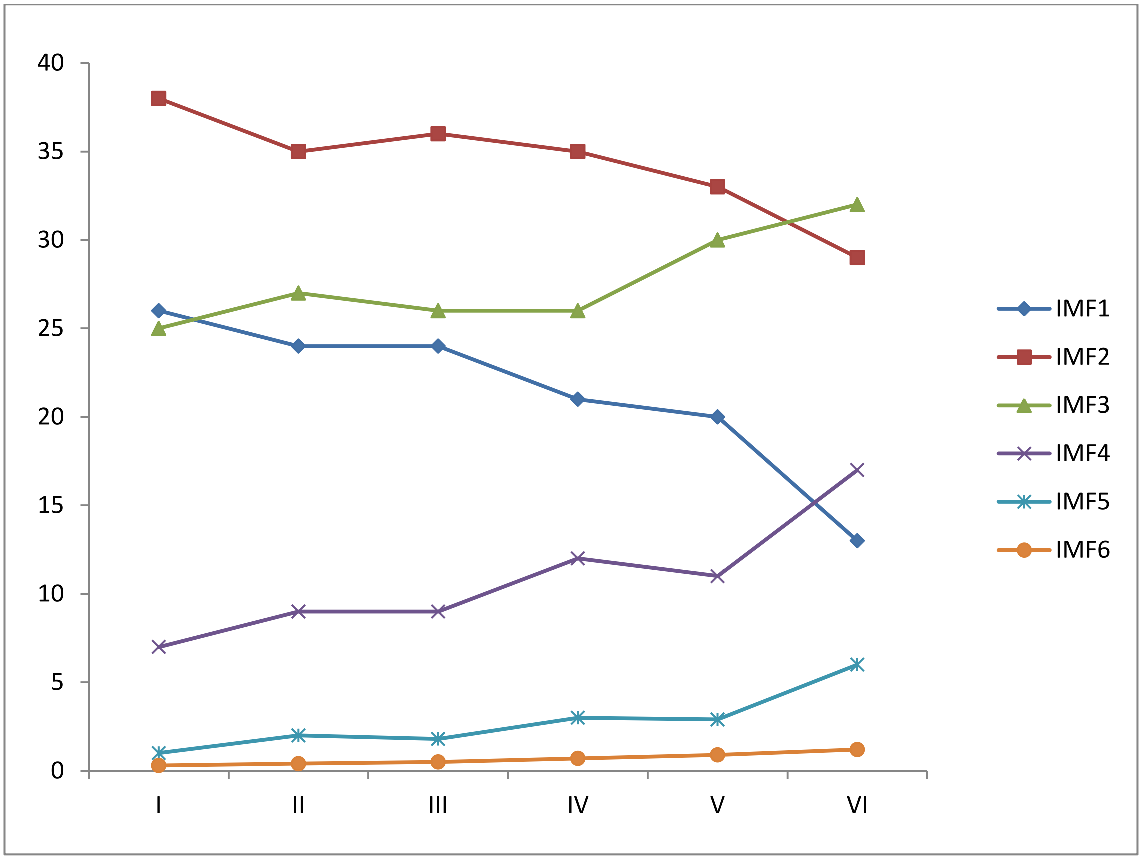
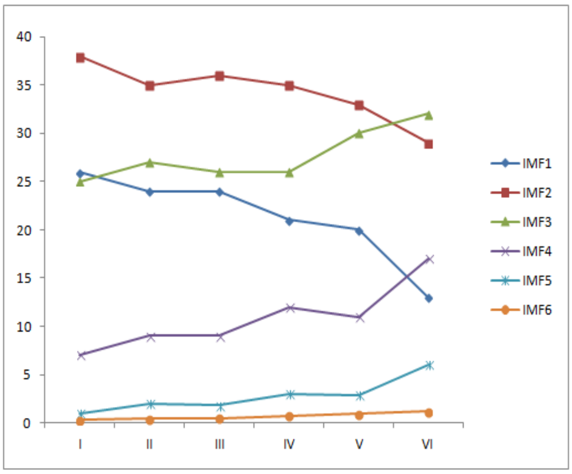
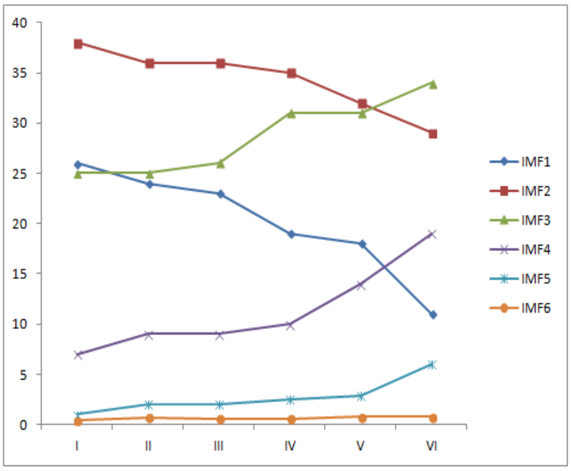


Figure 4.4 Percentage of IMFs for right masseter muscle.

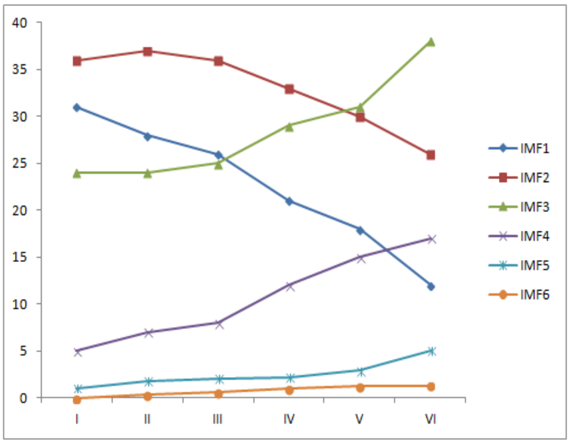
Comparison of the two sides and comparison of the two muscles are shown in Figure 4.5. As it was in Figure 4.2, the top row contains the graphs for the right side, while the bottom row contains the graph for the left side. Moreover, the first column contains the graph for the masseter muscle, while the second column contains the graph for the temporalis muscle. The patterns in the four figures are similar. There exists a decrease in the first two IMFs' percentage values within the signal. Besides, there is an increase in the other four IMFs' percentage value while progressing from Group I to Group VI. However, this time, there is no such distinct difference between the right and the left or between the masseter and the temporalis muscles. It is not easy to make a generalization about the amount of the decrease or increase in the average percentage values.



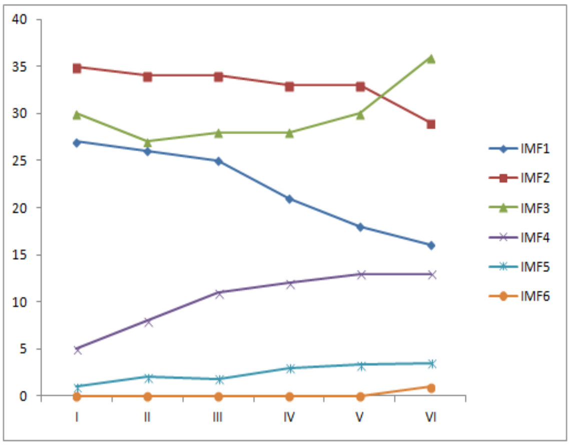
a) Percentage of IMFs for right masseter muscle.



b) Percentage of IMFs for right temporalis muscle.



c) Percentage of IMFs for left masseter muscle.



d) Percentage of IMFs for left temporalis muscle.

Figure 4.5 In second statistical calculation, comparison of right-left and masseter-temporalis muscles.

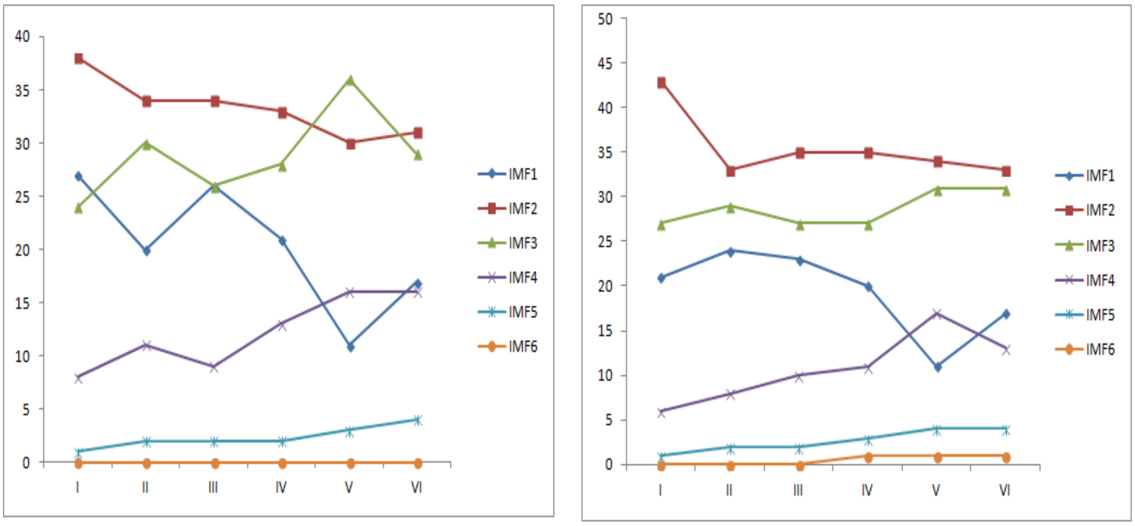
One-way MANOVA test results are shown in Table 4.2. The results were calculated and written for four muscles separately. For each muscle, the MANOVA test was applied for all IMFs one by one. For instance, the first row of table shows the p-values of right masseter muscle for each IMFs (from IMF1 to IMF6). The p-values obtained for each IMFs were calcuated among 6 groups of patients.

Except one p-value of right masseter muscle (Right M1) and one p-value of right temporalis muscle (Right M3), all p-values are less then 0.05. These results represents the meaningfulness of differences among groups' averages. For left side, masseter muscle (Left 2) gives better results compared to temporalis muscle (Left 4). The p-values for left temporalis muscle are all higher then 0.05 except the one for IMF1. The least meaningful results were obtained from left temporalis muscles.

Table 4.2 Comparision of p-values of four individual muscles for second calculation.

	IMF1	IMF2	IMF3	IMF4	IMF5	IMF6
Right M1	0.0032	0.0023	0.0538	9.91e-005	2.67e-007	0.0003
Right M3	2.27e-005	0.0096	0.0099	0.0002	0.0145	0.0548
Left M2	0.0054	0.126	0.0045	0.0138	0.011	0.0007
Left M4	0.0249	0.8471	0.1834	0.2036	0.2838	0.2656

Once again, because the data on the opposite-side muscles were available, the average results of the opposite-side muscles were looked into as well. Not surprisingly, those results do not exhibit a strong correlation compared to the results in Figure 4.5. For instance, the results of the right-side muscles are shown in Figure 4.6. The data for the right-side muscles were obtained while left-side chewing was being performed. Concequently, the results are nonsense comparied to Figure 4.5.



a) Graph of right masseter muscle while left chewing.

a) Graph of right temporalis muscle while left chewing.

Figure 4.6 Graph of right muscles during chewing on left side.

DISCUSSION

The application of EMD is widely used for the analysis of nonlinear and nonstationary signals, such as biosignals [16]. SVD has also been used in signal analysis to decontaminate the signal from noise [30, 32-35]. Using EMG signal is a common method in most of studies related to dental health or jaw muscles [56-61]. In this study, the application of EMD and SVD on EMG is proposed to search out the effect of teeth missing on the jaw muscles. For this purpose, first, EMG data were obtained from the subjects who have different numbers of missing teeth. By EMD, the signal was decomposed into a total of 6 subbands. SVD was provided to decompose each subband into five singular values. Thus, the whole signal was reduced to 30 numerical values only. Finally, the statistical examinations were done on those 30 values to evaluate some correlations between these features and the number of teeth missing for subjects.

It is known that patients with fewer healthy remaining teeth have more chewing difficulty [62]. The proposed method provides concrete evidence of the performance decrease in the jaw muscles in the case of teeth missing. In general, all of these EMG analysis results demonstrate the masticatory performance deterioration in the case of teeth missing. Furthermore, it is obvious that more missing teeth results to worse mastication efficiency.

The distinctive difference between the groups are found in the results for the right-side chewing process, especially for the masseter muscle. Compared to the temporalis muscle or the left-side muscles, the results for the right masseter muscle were much more significant. The cause of this situation might be the extensive use of the right side rather than the left side of the human body. Additionally, this result may imply that the masseter muscle is more influenced by the loss of teeth compared to the temporalis muscle of the same side. The reason for this situation might be that the masseter muscle plays a bigger role in the chewing process according to the temporalis muscle.

This method may be used in the orthodontic treatments in order to measure the achievement of the applications done to patients. For example, it may help determine the compatibility of denture prosthesis or the progress of the adaptation process. It can be useful to specify the subtype of some orthodontic diseases. In general, this method may help measure how much a situation is close to the natural condition.

The limitation of this study is that the patients were grouped based on the number of their missing teeth only because this parameter is accepted as the most effective one on masticatory performance [12-14]. Nevertheless, the other parameters, such as age, gender, some other diseases, or even mood of the patient, may have an effect on the masticatory performance. Those parameters can also be considered to examine the effect of teeth missing on chewing performance more wholesomely.

CONCLUSIONS AND RECOMMENDATIONS

The results of present study showed that the deterioration in the jaw muscle activity is positively related to the number of missing teeth. It is observed that the changes in both the percentage values of IMFs within the EMG signals and the percentage values of singular values within the IMFs are directly proportional to the number of missing teeth. Based on this findings, it could be said that the characterictics of EMG signal is corrupted by the decrease in the teeth number.

This study can be improved by appliying same process on patient with near ages. In such a case, it is expected to give more reliable information for the effect of missing teeth on mastication efficiency. In the other hand, the improvment can be done by considering the patients with same number of missing teeth but different ages in order to see if there is an effect of age on chewing performance. In a word, some more restrictions in parameters are needed for this study to be improved.

REFERENCES

[1] Ritchie, C.S., Joshipura, K., Hung, H. C., and Douglass, C. W., (2002). "Nutrition as a mediator in the relation between oral and systemic disease: associations between specific measures of adult oral health and nutrition outcomes", Crit Rev Oral Biol Med, 13(3): 291-300.

[2] Walls, A.W., Steele, J. G., Sheiham, A., Marcenes, W., and Moynihan, P. J., (2000). "Oral health and nutrition in older people", J Public Health Dent, 60(4): 304-7.

[3] Abnet, C.C., Qiao, Y. L., Dawsey, S. M., Dong, Z. W., Taylor, P. R., and Mark, S. D., (2005). "Tooth loss is associated with increased risk of total death and death from upper gastrointestinal cancer, heart disease, and stroke in a Chinese population-based cohort", Int J Epidemiol, 34(2): 467-74.

[4] Schwahn, C., Polzer, I., Haring, R., Dorr, M., Wallaschofski, H., Kocher, T., et al., (2013). "Missing, unreplaced teeth and risk of all-cause and cardiovascular mortality", Int J Cardiol, 167(4): 1430-7.

[5] Tu, Y.K., Galobardes, B., Smith, G. D., McCarron, P., Jeffreys, M., and Gilthorpe, M. S., (2007). "Associations between tooth loss and mortality patterns in the Glasgow Alumni Cohort", Heart, 93(9): 1098-103.

[6] Nakata, M., (1998). "Masticatory function and its effects on general health", Int Dent J, 48(6): 540-8.

[7] Lang, N.P. and F. Muller, (2007). "Epidemiology and oral function associated with tooth loss and prosthetic dental restorations. Consensus report of Working Group I", Clin Oral Implants Res, 18 (3): 46-9.

[8] Heaton, K.W., Marcus, S. N., Emmett, P. M., and Bolton, C. H., (1988). "Particle size of wheat, maize, and oat test meals: effects on plasma glucose and insulin responses and on the rate of starch digestion in vitro", Am J Clin Nutr, 47(4): 675-82.

[9] Gambareli, F.R., Serra, M.D., Pereira, L.J., and Gavião, M.B.D., (2007). "Influence of measurement technique, test food, teeth and muscle force interaction in masticatory performance", Journal of Texture Studies, 38(1): 2-20.

[10] Lee, H.K., Lee, K. D., Merchant, A. T., Lee, S. K., Song, K. B., Lee, S. G., and Choi, Y. H., (2010). "More missing teeth are associated with poorer general health in the rural Korean elderly", Arch Gerontol Geriatr, 50(1): 30-3.

[11] Choe, H., Kim, Y. H., Park, J. W., Kim, S. Y., Lee, S. Y., and Jee, S. H., (2009). "Tooth loss, hypertension and risk for stroke in a Korean population", Atherosclerosis, 203(2): 550-6.

[12] Feldman, R.S., Kapur, K. K., Alman, J. E., and Chauncey, H. H., (1980). "Aging and mastication: changes in performance and in the swallowing threshold with natural dentition", J Am Geriatr Soc, 28(3): 97-103.

[13] Heath, M.R., (1982). "The effect of maximum biting force and bone loss upon masticatory function and dietary selection of the elderly", Int Dent J, 32(4): 345-56.

[14] Kohyama, K., Mioche, L., and Bourdiol, P., (2003). "Influence of age and dental status on chewing behaviour studied by EMG recordings during consumption of various food samples", Gerodontology, 20(1): 15-23.

[15] Kara, S., Tokmakçı, M., Şişman, Y., Ertaş, E. T., İmal, E., and Özçoban, M. A., (2009). "Study of Electromyographic Signals During Chewing Process In Patients with Fixed Partial Denture", in 4th European Conference of the International Federation for Medical and Biological Engineering; Sloten, J., Verdonck, P., Nyssen, M., Hauesien, J., Springer Berlin Heidelberg. 1471-1474.

[16] Huang, N.E., Shen, Z., Long, S. R., Wu, M. L. C., Shih, H. H., Zheng, Q. N., Yen, N. C., Tung, C. C., Liu, H. H., (1998). "The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis", Proceedings of the Royal Society of London Series a-Mathematical Physical and Engineering Sciences, 454(1971): 903-995.

[17] Karagiannis, A. and Constantinou, Ph., (2009). "Electromagnetic Radiation Monitoring time Series Analysis Based on Empirical Mode Decomposition", BIOEM.

[18] Burr, T., (2009). "Hilbert-Huang Transform Analysis of Hydrological and Environmental Time Series. Eos", Transactions American Geophysical Union, 90(22): 194-194.

[19] Huang, N.E., Wu, M.-L., Qu, W., Long, S.R., and Shen, S.S.P., (2003). "Applications of Hilbert–Huang transform to non-stationary financial time series analysis", Applied Stochastic Models in Business and Industry, 19(3): 245-268.

[20] Torres, A., Fiz, J. A., Jane, R., Galdiz, J. B., Gea, J., and Morera, J., "Application of the empirical mode decomposition method to the analysis of respiratory mechanomyographic signals", Conf Proc IEEE Eng Med Biol Soc, 1566-9.

[21] Blanco-Velasco, M., Weng, B., and Barner, K.E., (2008). "ECG signal denoising and baseline wander correction based on the empirical mode decomposition",. Computers in Biology and Medicine, 38(1): 1-13.

[22] Charleston-Villalobos, S., Gonzalez-Camarena, R., Chi-Lem, G., and Aljama-Corrales, T., (2007). "Crackle sounds analysis by empirical mode decomposition. Nonlinear and nonstationary signal analysis for distinction of crackles in lung sounds", IEEE Eng Med Biol Mag, 26(1): 40-7.

[23] Echeverría, J.C., Crowe, J. A., Woolfson, M. S., and Hayes-Gill, B. R., (2001). "Application of empirical mode decomposition to heart rate variability analysis", Medical and Biological Engineering and Computing, 39(4): 471-479.

[24] Nimunkar, A.J. and Tompkins, W.J., (2007). "R-peak detection and signal averaging for simulated stress ECG using EMD", Conf Proc IEEE Eng Med Biol Soc, 1261-4.

[25] Krupa, B.N., Mohd Ali, M.A., and Zahedi, E., (2009). "The application of empirical mode decomposition for the enhancement of cardiotocograph signals", Physiol Meas, 30(8): 729-43.

[26] Tufan K, (2013). "Noninvasive diagnosis of atherosclerosis by using empirical mode decomposition, singular spectral analysis, and support vector machines", Biomedical Research, 24 (3): 303-312.

[27] Klema, V. and Laub, A.J., (1980). "The singular value decomposition: Its computation and some applications", Automatic Control, IEEE Transactions on, 25(2): 164-176.

[28] Broomhead, D.S. and King, G.P., (1986). "Extracting qualitative dynamics from experimental data", Physica D: Nonlinear Phenomena, 20(2–3): 217-236.

[29] Hemon, C.H. and Mace, D., (1978). "Essai d'une application de la transformation de karhunen-loève au traitement sismique", Geophysical Prospecting, 26(3): 600-626.

[30] Scharf, L.L., (1991). "Statistical Signal Processing: Detection, Estimation, and Time Series Analysis", Addison-Wesely, New York.

[31] Gerbrands, J.J., (1981). "On the relationships between SVD, KLT and PCA", Pattern Recognition, 14(1–6): 375-381.

[32] Ursin, B. and Zheng, Y., (1985). "Identification of seismic reflections using singular value decomposition", Geophysical Prospecting, 33(6): 773-799.

[33] Vrabie, V.D., (2003). "Statistiques d'ordre supèrieur: applications en gèophysique et èlectrotechnique", France.

[34] L. Mari, L.J., Glangeaud, F., and Coppens, F., (1999). "Signal Processing for Geologists & Geophysicists". Technip, Paris.

[35] Bob A.H., (1992). "Crosswell Seismology and Reverse VSP", Geophysical Press , London.

[36] Van der Veen, A.J., Deprettere, E.F., and Swindlehurst, A.L., (1993). "Subspace-based signal analysis using singular value decomposition", Proceedings of the IEEE, 81(9): 1277-1308.

[37] Patidar, M., Jain, N., and Agrawal, P., (2013). "EMG Signals classification based on singular value decomposition and neural network", International Journal of Scientific & Engineering Research, 4(6).

[38] Soylu, A.R., (2008). "Assessment of repeatability of surface electromyography signals by singular value decomposition", Journal of Electromyography and Kinesiology, 18(4): 690-694.

[39] National Digestive Diseases Information Clearinghouse, The Digestive System and How It Works, http://digestive.niddk.nih.gov/ddiseases/pubs/yrdd/, 10 April 2014.

[40] Los Altos Feeding Clinic, Anatomy of the Gastrointestinal Tract, http://www.pediatricfeeding.org/gi_anatomy.html, 5 April 2014.

[41] N'Gom, P.I. and Woda, A., (2002). "Influence of impaired mastication on nutrition", J Prosthet Dent, 87(6): 667-73.

[42] Guillaume, C., (1984). "L'edentation: ses causes, ses consequences, ses traitements: enquete aupres de deux populations de personnes agees; milieu domiciliaire et secteur moyen et long sejour".

[43] Consumer guide to dentistry, Edentulism: Causes and Consequences of Tooth Loss, http://www.yourdentistryguide.com/tooth-loss/, 15 April 2014.

[44] Reaz, M.B.I., Hussain, M.S., and Mohd-Yasin, F., (2006). "Techniques of EMG signal analysis: detection, processing, classification and applications", Biological Procedures Online, 8(1): 11-35.

[45] Okkesim, S., Uysal, T., Baysal, A., Kara, S., (2012). "EMG PSD Measures in Orthodontic Appliances", in EMG Methods for Evaluating Muscle and Nerve Function, Edited by Mark Schwartz, InTech: 491-506.

[46] Hermens, H.J., Freriks, B., Disselhorst-Klug, C., (2000). "Development of recommendations for SEMG sensors and sensor placement procedures". J Electromyogr Kinesiol, 10(5): 361-74.

[47] Scholarpedia, Hilbert-Huang transform, http://www.scholarpedia.org/article/Hilbert-Huang_transform, 12 March 2014.

[48] Diop, E.H.S., Alexandre, R., and Moisan, L., (2012). "Intrinsic nonlinear multiscale image decomposition: A 2D empirical mode decomposition-like tool", Computer Vision and Image Understanding, 116(1): 102-119.

[49] Rilling, G., Flandrin, P., and Goncalves, P., (2003). "On empirical mode decomposition and its algorithms", Proceedings of IEEE EURASIP Workshop on Nonlinear Signal and Image Processing, Grado(I).

[50] Chan, T.F., (1982). "An Improved Algorithm for Computing the Singular Value Decomposition", ACM Trans. Math. Softw., 8(1): 72-83.

[51] Jung, J., YuHua, H., Xian, L., and Zheng, H., (2007). "Feature Extraction of Pulse Signal Based on Hilbert-Huang Transformation and Singular Value Decomposition", in Bioinformatics and Biomedical Engineering, ICBBE 2007. The 1st International Conference on.

[52] Zhang, X., (2004). Matrix Analysis and Application, Tsinghua University Press Beijing, China.

[53] Golub, G.H., and Van Loan, C.F., (1996). "Matrix computations". third ed., Johns Hopkins Univ. Press, Baltimore,US.

[54] Strang, G., (1998). "Linear Algebra and its Applications", Third ed, ed. T. Brooks/Cole.

[55] Pozzo, M., Farina, D., and Merletti, R., (2004). "Electromyography:Detection, Processing and Applications Biomedical Technology and Devices Handbook", ed. C. press.

[56] Mioche, L., Bourdiol, P., Monier, S., Martin, L.F., and Cormier, D., (2004). "Changes in jaw muscles activity with age: effects on food bolus properties", Physiology & Behavior, 82: 621– 627.

[57] Uysal, T., Yagci, A., Kara, S., and Okkesim, S., (2012)." Influence of pre-orthodontic trainer treatment on the perioral and masticatory muscles in patients with Class II division 1 malocclusion", Eur J Orthod, 34(1): 96-101.

[58] Akdenur, B., Okkesum, S., Kara, S., and Gunes, S., (2009). "Correlation- and covariance-supported normalization method for estimating orthodontic trainer treatment for clenching activity", Proc Inst Mech Eng H, 223(8): 991-1001.

[59] Ferrario, V.F., Tartaglia, G. M., Galletta, A., Grassi, G. P., and Sforza, C., (2006). "The influence of occlusion on jaw and neck muscle activity: a surface EMG study in healthy young adults", J Oral Rehabil, 33(5): 341-8.

[60] Karkazis, H.C. and Kossioni, A.E., (1998). "Surface EMG activity of the masseter muscle in denture wearers during chewing of hard and soft food", J Oral Rehabil, 25(1): 8-14.

[61] Karkazis, H.C., (2002). "EMG activity of the masseter muscle in implant supported overdenture wearers during chewing of hard and soft food", J Oral Rehabil, 29(10): 986-91.

[62] Hsu, K.J., Yen, Y.Y., Lan, S.J., Wu, Y.M., Chen, C.M., and Lee, H.E., (2011). "Relationship between remaining teeth and self-rated chewing ability among population aged 45 years or older in Kaohsiung City, Taiwan", Kaohsiung J Med Sci, 27(10): 457-65.

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